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A Framework for Addressing Circularity Challenges in Cities with Nature-Based Solutions

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Abstract: A novel framework is presented that aims to guide practitioners and decision makers toward a better understanding of the role of nature-based solutions (NBS) in the enhancement of resources management in cities, and the mainstreaming of NBS in the urban fabric. Existing frameworks describing the use of NBS to address urban challenges do not specifically consider circularity challenges. Thus, the new framework provides the following: (1) a comprehensive set of Urban Circularity Challenges (UCCs); (2) a set of more than fifty NBS units and NBS interventions thoroughly assessed in terms of their potential to address UCCs; and (3) an analysis of input and output resource streams, which are both required for and produced during operation of NBS. The new framework aims to facilitate the coupling of individual NBS units and NBS interventions with NBS that enable circular economy solutions.

Keywords: water; resources management; circularity challenges; circular cities

1. Introduction

Despite significant efforts to become more sustainable in managing their resources, cities still represent a big burden to the environment. As the urban population grows, so does the demand for new resources (water, food, energy, materials), coupled with high levels of pollution and ecosystems degradation. Climate change impacts exacerbate the existing environmental problems. Many cities have adopted strategies for sustainable development and a sensible use of resources, e.g., Amsterdam, Copenhagen, Rotterdam [1,2], but unfortunately, the reality is that the majority of cities still follows the typical linear urban metabolism, causing a huge environmental footprint.

In pursuit of sustainability, cities are increasingly putting nature-based solutions (NBS) in the spotlight because of their high potential to address several urban challenges related to resources management in cities such as climate adaptation and mitigation, sustainable consumption and production, air quality, and water management [3–5]. In this work, we use the definition of the COST Action CA17133 Circular City [6] whereby NBS are defined as "concepts that bring nature into cities and those that are derived from nature. . . . As such, within this definition we achieve resource recovery using organisms (e.g., microbes, algae, plants, insects, and worms) as the principal agents. However, physical and chemical processes can be included for recovery of resources, as they may be needed for supporting and enhancing the performance of NBS".

There are several frameworks assessing urban challenges and how they can be effectively addressed by NBS [3,4,7,8]. However, very few existing frameworks put forward urban challenges from the perspective of enhancing the circularity of resources management in cities and ensuring a sustainable urban development. While the framework from the EKLIPSE report [3,4] and the International Union for Conservation of Nature [7] identifies a series of general urban challenges mainly focused on societal, economic, and environmental urban challenges targeted by NBS, the Nature4Cities framework [9] fosters a set of urban challenges that embraces circularity topics in terms of the potential of NBS to promote resource efficiency (e.g., food, energy and water, raw materials, waste, recycling) and green economy (e.g., circular economy, bioeconomy activities, direct economic value of NBS). While this Nature4Cities framework is very valuable in terms of establishing much needed order in a burgeoning field, we believe there is room for the development of a comprehensive list of Urban Circularity Challenges (UCCs) in line with the detailed description of how and to which extent NBS can address such challenges.

Therefore, this research is aimed at narrowing down the list of relevant urban challenges and the interrelations between these frameworks while retaining the necessary information and level of complexity to adequately address the circularity issues at hand. For this purpose, we employ the concept of circular economy (CE), i.e., the circular management of resources in cities through the deployment of NBS. CE has three core principles [10]: (i) the first principle, 'regenerate natural capital', ensures functional environmental flows and stocks, by reducing the use of resources, preserving and enhancing ecosystems, and ensuring minimal disruptions from human interactions and use; (ii) the second principle of 'keep resources in use' is to close material loops and minimize energy loss within the system, which is achieved by optimizing resource yields, optimizing energy and resource extraction, and maximizing their recycling and reuse; and (iii) the third principle, 'design out waste externalities', focuses on the reduction and the residual waste of the system, including economic efficiency. The costs of reducing waste by one unit should be equal to the economic and environmental benefits of having one fewer unit of waste [10,11]. Circularity is viewed here as a strategic approach that helps cities shift from a linear to a circular metabolism, i.e., cities that thrive without demanding too many resources and/or producing waste [12,13] by the implementation of a circular framework for the design and operation of NBS in cities.

Therefore, we propose a framework for addressing UCCs with NBS, which aims to guide practitioners and decision makers toward a better understanding of the role of NBS in the enhancement of resources management in cities and the mainstreaming of NBS in the urban setting. The framework includes the following: (1) a comprehensive set of UCCs based on gaps identified in existing frameworks as proposed by [14]; (2) a set of more than fifty NBS units and interventions (NBS_u/i) assessed in terms of their potential to address UCCs and classified according to the following categories proposed by [15]: nature-based solutions units (NBS_u) defined as "stand-alone green technologies or green urban spaces, which can be combined with other solutions (nature-based or not)" and NBS interventions (NBS_i) defined as "the act of intervening in existing ecosystems and in NBS_u, by applying techniques to support natural processes". This list also includes several Supporting units (S_u) that are required to create CE through NBS; and (3) a systematic approach for defining input and output (I/O) resource streams to and from NBS units/interventions that support creating CE through NBS. Such conceptual and empirical advancement is crucial in order to support the transition from current linear design paradigms to a more circular one when dealing with NBS in urban settlements.

2. Materials and Methods

2.1. A Novel Set of Urban Circularity Challenges (UCCs)

The existing urban challenges frameworks developed by EKLIPSE and Nature4Cities related to resource efficiency [3,4,9] were the starting point for identifying the UCCs used in this study [14]. When it comes to CE and the circular management of resources, a more specific targeted approach is required, and hence, the challenges are defined in a more detailed manner. The issues identified are mostly related to resources management according to the CE principles set by the Ellen MacArthur Foundation [10], namely 'regenerate natural capital', 'keep resources in use', and 'design out waste externalities'.

Implementing these principles for the management of resources in cities would enable an urban transition to circularity. The two obvious challenges for this achievement are [14]:

1. How to minimize the import and consumption of new resources; and
2. How to minimize waste production.

Considering four vital resources, i.e., water, food, energy, and materials, a series of workshops with expert groups were held to break down the two major challenges into a feasible set of challenges related to the observed resources, and for implementing circular resources management in cities. The expert groups are interdisciplinary, and they include a diverse set of professionals and researchers ranging from civil, sanitary, and environmental engineers, architects, urban and landscape planners, natural scientists, agronomists, social scientists, etc. These experts make up the members of the five individual working groups (WGs) formed within the COST Action Circular City (https://circular-city.eu/ (accessed on 30 June 2021)): Built Environment (WG1), Sustainable Urban Water Utilization (WG2), Resource Recovery (WG3), Urban Farming (WG4), and Transformation Tools (WG5).

2.2. List of Nature-Based Solutions (NBS) Units and Interventions (NBS_u/i) for Addressing Urban Circularity Challenges (UCCs)

Implementing NBS for addressing circularity challenges requires the coupling of several units and/or interventions. The list of NBS_u/i addressing UCCs offers a systematic approach for defining the terminology related to and the classification of NBS. A list of thirty-two NBS_u/i proposed by Castellar et al. [15] was used in this study as a baseline for defining the set of NBS for addressing UCCs [14]. The development of the baseline list of thirty-two NBS included a comprehensive analysis of more than two hundred NBS described by four European Horizon 2020 projects: Urban GreenUP (https://www.urbangreenup.eu/ (accessed on 30 June 2021)), UNaLab (https://unalab.eu/en (accessed on 30 June 2021)), Nature4Cities (https://www.nature4cities.eu/ (accessed on 30 June 2021)), and ThinkNature (https://www.think-nature.eu/ (accessed on 30 June 2021)); coupled with mixed quantitative–qualitative approaches such as dedicated workshops, interviews with experts and surveys (for more details concerning the methodology, please consult [15]).

Next, a series of five elicitation workshops adapted from the IDEA ("investigate", "discuss", "estimate", and "aggregate") protocol [16,17] were carried out between June and December 2020 in order to achieve the following: (i) refine the list of NBS, and thus, provide a comprehensive list of NBS for addressing UCCs; (ii) evaluate the NBS according to their ability to address the UCC; and (iii) categorize the NBS. The elicitation workshops were prepared under the scope of the COST Action Circular City and brought together—in each workshop—more than sixty NBS experts with wide and diverse backgrounds (i.e., urban planners, architects, engineers, researchers, social scientists, etc.) from more than thirty countries. The following methodology was applied during the five elicitation workshops:

(i) Development of NBS list: The baseline list of thirty-two NBS_u/i [15] and new NBS_u/i proposed by participants of the workshops were evaluated according to the following eligibility criteria. First, in order to properly cover the scope of the current research, i.e., NBS for resources circularity in cities, the NBS should be in line with the definition of NBS proposed under the COST Action Circular City [6], which in contrast to existing definitions [7,18–21] "transfers the NBS concept into urban areas, putting a special emphasis on resource circularity" [15]. Additionally, physical and chemical processes/technologies for supporting NBS and enhancing their performance have been included as Supporting units (S_u). Second, to avoid duplication issues, the new NBS_u/i proposed by participants must not already be contained in the baseline list of thirty-two NBS_u/i, for example in the case of an already featured unit being listed under a different name. Finally, NBS_u/i should address at least one of the identified UCCs [14];

(ii) Evaluation of NBS potential to address UCCs: To assess the fulfillment of the final eligibility criterion, a special session was conducted, in which a qualitative evaluation of the NBS_u/i that had been selected up until that point was performed. Experts were divided into the COST Action's WGs to discuss the potential of each NBS_u/i for addressing the identified UCCs. They were asked to decide by means of consensus to which degree a given NBS contributes to the achievement of a particular UCC. A four-point scale with respective criteria was defined to represent the degree of contribution to the UCC: (1) the NBS_u/i fully addresses the UCC (score = 1); (2) the NBS_u/i contributes to managing/overcoming the challenge (Score = 0.67); (3) the NBS_u/i—depending on the design—has the potential to contribute to overcoming a given UCC (Score = 0.33); and (4) the NBS_u/i does not address the UCC (Score = 0.0). If it was determined that a particular NBS_u/i failed to address any of the UCCs, it was excluded from the list. To assess the ability of NBS_u/i to address UCCs, we calculated the following global scores: the "UCC global score" is computed by a simple averaging of the NBS_u/i scores for each UCC, and the "NBS global score" is computed by a simple averaging of the UCC scores for each NBS_u/i. Additionally, we counted the number of NBS related to each UCC and the number of UCCs related to each NBS_u/i.

(iii) NBS classification: The resulting set of selected NBS_u/i was classified according to the two categories [15]: NBS_u, which includes NBS spatial units (NBS_su) and NBS technological units (NBS_tu); and NBS_i, which includes NBS soil and river interventions (NBS_is and NBS_ir). As mentioned above, S_u were considered in addition to the classification scheme described here [15]. Next, NBS_u/i including S_u were clustered into sub-categories based on similar technical features, characteristics, and properties for their design, implementation, and functioning in line with their specific purposes. Finally, in further sessions, participants refined the descriptions and nomenclature, and they suggested synonyms for the selected NBS_u/i according to existing standards and literature.

2.3. Nature-Based Solutions (NBS) Circularity: Input and Output (I/O) Streams

In order to overcome the existing deficiencies in urban resource management through the use of NBS in cities, their input and output (I/O) streams need to be defined [22]. Resources required, used, or produced during the operation and maintenance of NBS were identified by a consortium of experts, which included participants from all WGs of the COST Action Circular City. The identification and data collection were done in two stages. In stage one, each WG individually addressed the NBS recognized as relevant to their respective WG. The collection and definition of I/O followed a disciplinary approach, whereby each individual NBS was analyzed based on the state of the art of the individual field of application. The approach was grounded in the need to identify the I/O necessary for operation and maintenance, and the selection was based on physical, chemical, and biological properties. In the second stage, experts from all WGs collaborated in grouping the assembled I/Os into streams [22]. This stage was intentionally conceived to cut across all disciplines (WGs) in order to eliminate the disciplinary bias from step one.

3. Results and Discussion

3.1. Urban Circularity Challenges (UCCs)

The UCCs identified by [14] for shifting to circular management of resources with NBS (Figure 1) are as follows:

- UCC_1: Restoring and maintaining the water cycle;
- UCC_2: Water and waste treatment, recovery and reuse;
- UCC_3: Nutrient recovery and reuse;
- UCC_4: Material recovery and reuse,
- UCC_5: Food and biomass production;
- UCC_6: Energy efficiency and recovery; and
- UCC_7: Building system recovery.

During the participatory approaches carried out in the scope of the COST Action Circular City (see Section 2.1), the UCCs were refined. As a result, detailed descriptions for each UCC as well as the role of NBS_u/i (NBS_u/i) in addressing such challenges are presented in Table A1.

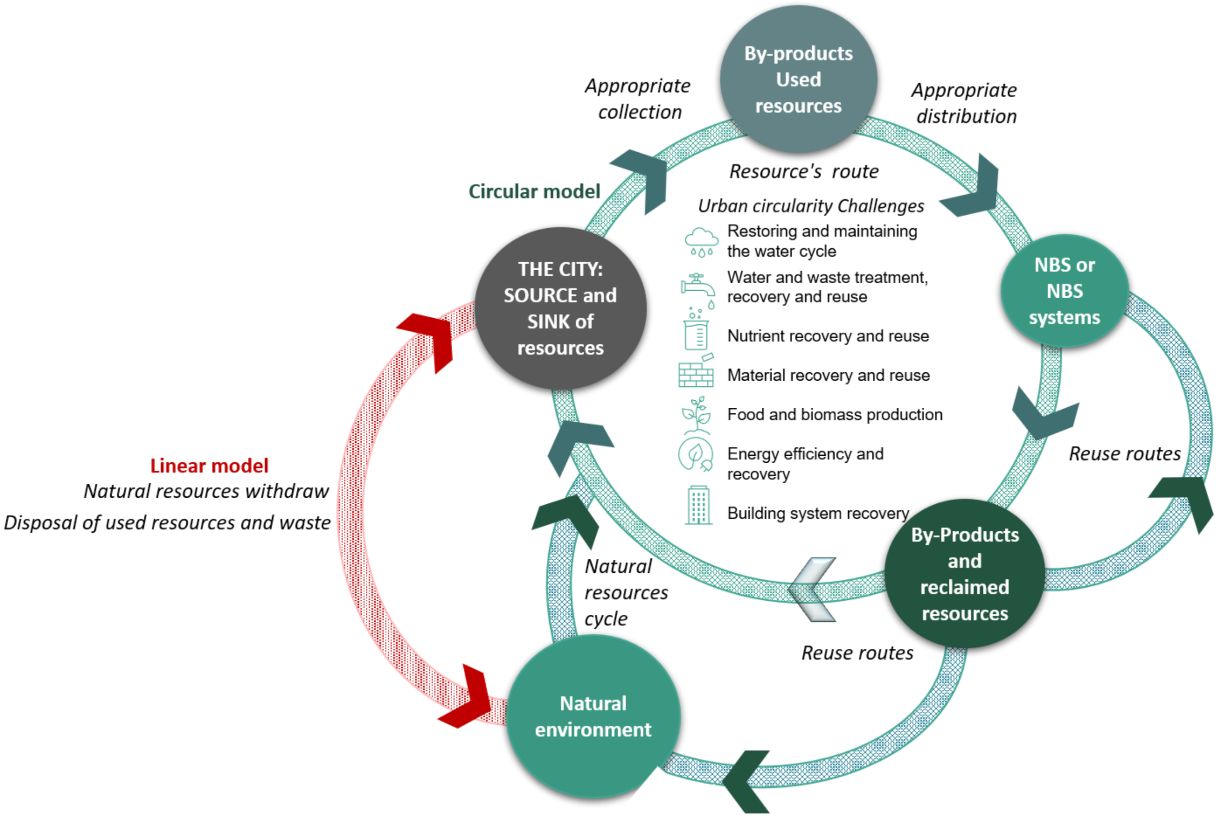

Figure 1. Urban circularity challenges addressed by NBS implemented under a circular framework (adapted from [14]).

The societal challenges addressed by NBS are numerous, ranging from resource recovery to climate change mitigation, ecosystem restoration, and many more. Widespread and successive implementation of NBS will help in climate regulation, both on a micro and macro scale. Considering the limited space in urban areas and the competition for use of open spaces, it is of great importance to focus on providing NBS that contribute to resolving the widest possible range of the above-listed challenges. By implementing NBS in a purposeful way, with multifunctionality and interdisciplinarity in mind, a broader contribution can be made toward achieving a circular management of limited resources. This will also provide economic benefits, as the implementation of multipurpose NBS over single-purpose NBS frees up financial and material resources to be used elsewhere. It is important to ensure cooperation at all stages of NBS implementation, between engineers, architects, landscape planners, politicians, end-users, and any other stakeholder party that is willing and interested to be a part of the discussion. A concerted effort for the broad involvement of stakeholder groups, iterative co-design and implementation processes, and effective communication strategies should be emphasized.

3.2. List of Nature-Based Solutions Units and Interventions for Addressing Urban Circularity Challenges (UCCs)

Resulting from a series of elicitation workshops, we propose a comprehensive list of fifty-one NBS_u and NBS_i, and ten S_u for addressing the UCCs proposed by [14]. During the process, the following three NBS_u/i listed in Castellar et al. [15] were excluded, as they do not address any of the UCCs: "Create and preserve habitats and shelters for biodiversity", "Heritage garden", and "Use of pre-existing vegetation". Moreover, we propose a set of sub-categories for NBS that facilitates the understanding of implicit, but sometimes subtle, relations between the purpose of NBS and some specific requirements concerning technical features for design and implementation.

During the workshops, we determined that the purpose of an NBS_u/i can be related to the technological role/main application goal (e.g., urban rainwater management or food and biomass production), to their greening role at different scales (e.g., public green spaces or vertical greening systems and green roofs) or to their practical application (e.g., soil and water bioengineering). These interrelations were used as bases to cluster the NBS (Figure 2). The resulting NBS sub-categories are described below:

- *Rainwater Management:* This sub-category contains all NBS for rainwater management. These NBS (mainly NBS_tu) are also known as sustainable urban drainage systems (SUDS), low impact development (LID), best management practices (BMPs), water-sensitive urban design (WSUD), etc. [23]. They enable stormwater management, increased infiltration, removal of pollutants, improved quality of runoff, mitigation of flash floods, increased biodiversity, and reduced urban heat island effect;
- *Vertical Greening Systems and Green Roofs:* This sub-category contains NBS_tu for the main types of vertical greening and green roofs. These NBS increase urban biodiversity, decrease the urban heat island effect, improve stormwater management, lower energy consumption, reduce noise, improve air quality, and provide relaxation and socialization areas;
- *Remediation, Treatment, and Recovery:* This group features NBS_u and NBS_i for remediation, treatment, and recovery, and it includes a high number of S_u. These S_u might be a particular requirement for the recovery of resources;
- *(River) Restoration:* This sub-category includes a set of NBS_i related to techniques for river restoration aimed at reducing flood risk and erosion, increasing channel storage capacity, redirecting the water flow, and improving the diversity of riverine species;
- *Soil and Water Bioengineering:* This sub-category includes a set of NBS_i related to soil and water bioengineering techniques. Such NBS_i enhance soil quality, increase carbon storage, decrease soil compaction, minimize/prevent soil erosion, and enhance riverbank protection and hillside stabilization;
- *(Public) Green Space:* This sub-category includes NBS_su that are mainly larger in size and aimed at renaturing cities, controlling urban sprawl, providing niches for urban wildlife and recreational areas for citizens, controlling stormwater, improving air quality, and increasing urban biodiversity; and
- *Food and Biomass Production:* This sub-category comprises NBS_tu and NBS_su for food and biomass production. Additionally, these technologies can generate income, decrease the use of resources and space, and enhance community building.

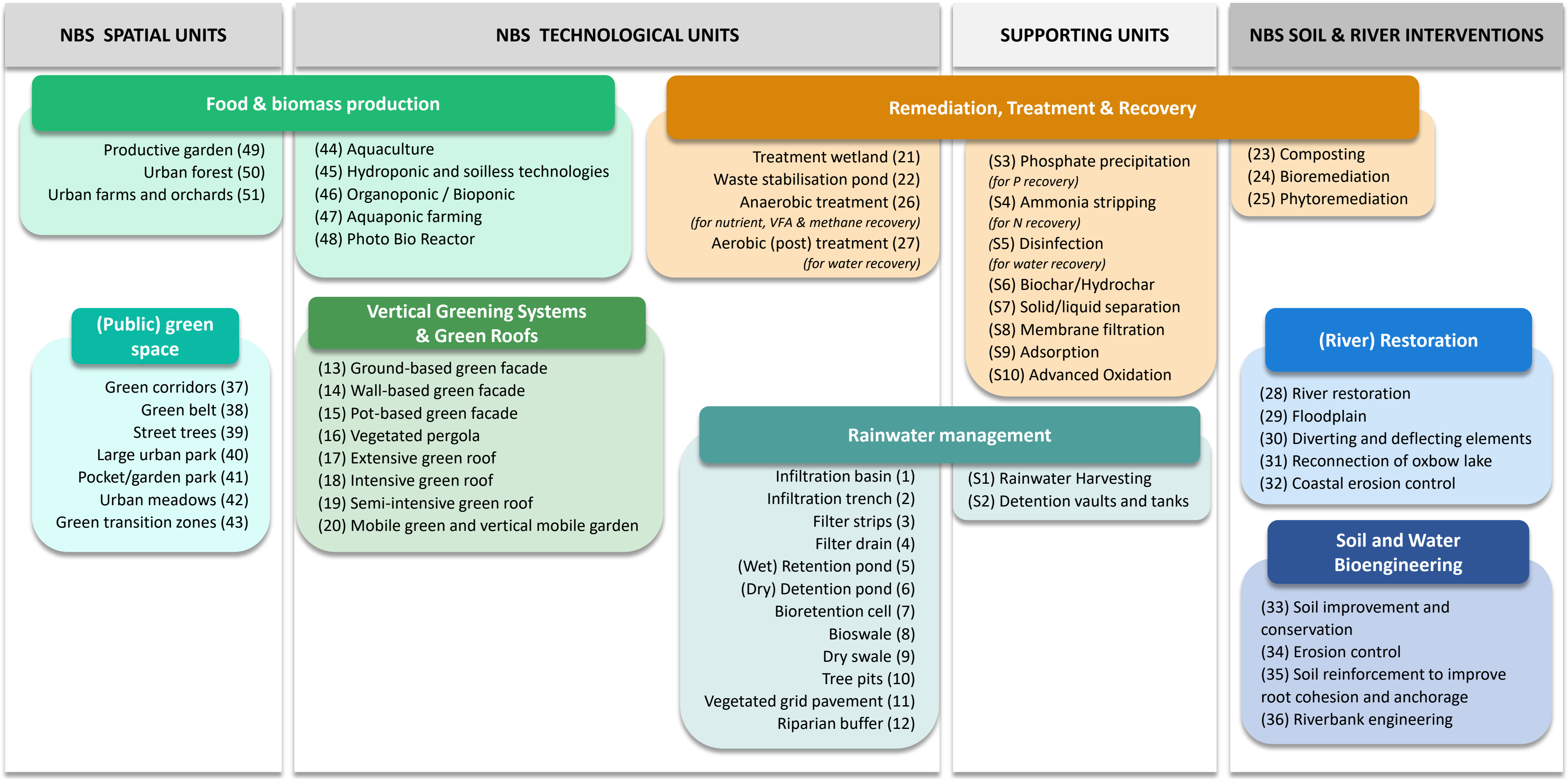

Figure 2. NBS units (NBS_u), NBS interventions (NBS_i), and Supporting units (S_u) clustered into categories (dark gray squares, adapted from [15] and sub-categories proposed by consulted experts within the COST Action Circular City (colored squares).

The presented categories are conceptually fine-tuned and concise enough to guide practitioners and experts in better understanding and assessing the role and relevance of individual NBS in the urban environment. Thus, it may facilitate the selection of the most suitable NBS units and interventions for specific needs and expectations. Moreover, the criteria used to classify the NBS are consistent, setting the proposed classification scheme apart from previous classification attempts [24–27] that are mostly based on hierarchical structures. The above-presented classification scheme adds value by cutting across different category levels, which is a feature that reflects the transversality and multifunctionality of NBS. For example, "Productive garden" and "Aquaponic farming" are both NBS from the "*Food and biomass production*" sub-category, but the former was considered as an NBS_su and the latter as a NBS_tu. The same is true for "Treatment wetland" and "Composting", both NBS are considered to be part of sub-category "*Remediation, Treatment, and Recovery*"; however, the former is an NBS_tu and the latter is a soil intervention (NBS_is). Moving forward, the NBS_u, NBS_i, and S_u for addressing UCCs are sorted according to the sub-categories (described above) and presented in Figure 2 (synonyms and descriptions of NBS_u/i are provided in the Appendix A Table A2).

UCCs addressed by NBS_u/i and S_u are summarized in Table 1. From Table 1, it can be inferred that most NBS_u/i and S_u fully address the UCC_1 ("Restoring and maintaining water cycle"), and UCC_2 ("Water and waste treatment, recovery, and reuse"), while they address UCC_3 ("Nutrient recovery and reuse"), and UCC_4 ("Material recovery and reuse") the least. In addition, WG experts found that the NBS contributions toward overcoming circularity challenges is most evident for UCC_5 ("Food and biomass production"), while the potential contributions of NBS—depending on the design—are considered highest for UCC_4 ("Material recovery and reuse"). The potential is also apparent for further addressing UCC_6 ("Energy efficiency and recovery"), and UCC_7 ("Building system recovery"), as most NBS do not yet fully address them. At the level of individual NBS_u, experts recognized that semi-intensive green roofs, urban farms and orchards, and intensive green roofs contribute the most to solving the recognized UCC. Conversely, diverting and deflecting elements, soil reinforcement to improve root cohesion and anchorage, and coastal erosion control interventions were identified as contributing the least to resolving the UCC. These results indicate the need for further improvement of NBS, especially in order to address the challenges related to nutrient and material recovery and reuse (UCC_3 and UCC_4) in urban areas, which are currently covered least by available solutions.

"*Restoring and maintaining the water cycle*" (UCC_1), "*Water and waste treatment, recovery, and reuse*" (UCC_2), and "*Food and biomass production*" (UCC_5) received the highest UCC global scores: 0.77, 0.68, and 0.53, respectively (Figure 3). Moreover, almost all NBS_u/i were considered to have an impact on water-related UCC_1 and UCC_2, and approximately 78% of all NBS_u/i can address "*Food/biomass-related issues*" (UCC_5). Indeed, almost all NBS_u/i addressing food and biomass production also address water-related challenges, except for NBS such as "Aquaculture", "Composting", and "(River) restoration". This result highlights the multifunctionality of NBS as well as their great potential to restore the water cycle, promote water recovery and reuse, and, at the same time, provide food and biomass in urban settlements (e.g., "Aquaponic farming"). In contrast, the UCC "*Material recovery and reuse*" (UCC_4) received the lowest UCC global score, and only 18 NBS_u/i were related to this challenge. The above-described results indicate that the "circularity" frame of NBS is more explicit regarding the goal of keeping natural resources in use, as is the case with water and biomass. This fact might be explained by the way that NBS_u/i inherently function, in the sense that all NBS_u/i need water to function, and they produce biomass as an output. In contrast, the recovery and reuse of materials is not something intrinsic/vital to the design or functioning of NBS. On the contrary, this approach pushes the conventional design linear frame to move toward a more circular framework in terms of the management of material flows (input and outputs), thus encouraging the consideration of potential interactions between NBS_u/i and their surrounding environment, either by reusing/recovering material from local urban production chains (local INPUTs) or by providing valuable materials as, for example, organic compost to be used by urban farmers (local OUPUT).

Table 1. Urban Circularity Challenges (UCCs) addressed by NBS units (NBS_u), NBS interventions (NBS_i), and Supporting units (S_u) (● = addressing the challenge; • = contribution to challenge mitigation; ○ = potential contribution, depending on the design; and as an "empty cell" = not addressing the challenge). NBS_tu = technological units; NBS_su = spatial units; NBS_is = interventions; NBS_ir = river interventions; and S_u = Supporting unit.

Classification		(#) NBS Units, NBS Interventions, and Supporting Units	Urban Circularity Challenge: Restoring and Maintaining the Water Cycle	Water and Waste Treatment, Recovery and Reuse	Nutrient Recovery and Reuse	Material Recovery and Reuse	Food and Biomass Production	Energy Efficiency and Recovery	Building System Recovery
Rainwater Management	*NBS_tu*	(1) **Infiltration basin**	●	•			○	○	
		(2) **Infiltration trench**	●	○					
		(3) **Filter strips**	●	•					
		(4) **Filter drain**	●	•					
		(5) **(Wet) Retention pond**	●	•		○	○		
		(6) **(Dry) Detention pond**	●	•					
		(7) **Bioretention cell**	●	●	●	○	○		●
		(8) **Bioswale**	●	●			○		
		(9) **Dry swale**	●	○			○		
		(10) **Tree pits**	●	●	●		○	●	
		(11) **Vegetated grid pavement**	●	•			○	●	
		(12) **Riparian buffer**	●	●	●		•	○	
	S_u	(S1) **Rainwater harvesting**	●	○				●	○
		(S2) **Detention vaults and tanks**	●	○					●
Vertical Greening Systems & Green Roofs	*NBS_tu*	(13) **Ground-based green facade**	•	●			•	●	●
		(14) **Wall-based green facade**	●	●	○	○	●	●	●
		(15) **Pot-based green facade**	●	●	○		●	●	
		(16) **Vegetated pergola**	○	●		○	●	●	
		(17) **Extensive green roof**	●	○			●	●	●
		(18) **Intensive green roof**	●	●	○	○	●	●	●
		(19) **Semi-intensive green roof**	●	●	●	○	●	●	●
		(20) **Mobile green and vertical mobile garden**	○	●			•	○	
Remediation, Treatment & Recovery	*NBS_tu*	(21) **Treatment wetland**	●	●	○	○	•	●	○
		(22) **Waste stabilization pond**	●	●					
		(26) **Anaerobic treatment**	●	●	●	○		●	
		(27) **Aerobic (post) treatment**	●	●					
	NBS_is	(23) **Composting**			●	●	●	●	
		(24) **Bioremediation**	○	○		○			○
		(25) **Phytoremediation**	○	○	○	○	•		○

Table 1. *Cont.*

Classification		(#) NBS Units, NBS Interventions, and Supporting Units	Urban Circularity Challenge						
			Restoring and Maintaining the Water Cycle	Water and Waste Treatment, Recovery and Reuse	Nutrient Recovery and Reuse	Material Recovery and Reuse	Food and Biomass Production	Energy Efficiency and Recovery	Building System Recovery
Remediation, Treatment & Recovery	*S_u*	(S3) **Phosphate precipitation** (for P recovery)	●	●	●				
		(S4) **Ammonia stripping** (for N recovery)	●	●	●				
		(S5) **Disinfection** (for water recovery)	●	●					●
		(S6) **Biochar/Hydrochar production**	●	●		●	●		
		(S7) **Physical unit operations for solid/liquid separation**	●	●		●	·		●
		(S8) **Membrane filtration**	●	●		●			●
		(S9) **Adsorption**	●	●	○	○			
		(S10) **Advanced Oxidation Processes**	●	●					
(River) Restoration	*NBS_ir*	(28) **River restoration**	●	·			·		
		(29) **Floodplain**	●	·			·		
		(30) **Diverting and deflecting elements**	○						
		(31) **Reconnection of oxbow lake**	●	·					
		(32) **Coastal erosion control**	·				○		
Soil & Water Bioengineering	*NBS_is*	(33) **Soil improvement and conservation**	○	○	●	●	·		●
		(34) **Erosion control**	○	○	●		○		○
		(35) **Soil reinforcement to improve root cohesion and anchorage**	○						○
		(36) **Riverbank engineering**	○	○			○		
(Public) Green Space	*NBS_su*	(37) **Green corridors**	●	●			·		
		(38) **Green belt**	●	●			·		○
		(39) **Street trees**	●	●		○	·		○
		(40) **Large urban park**	●	●		○	·	○	○
		(41) **Pocket/garden park**	●	●		○	·	○	○
		(42) **Urban meadows**	●	●		○	·		○
		(43) **Green transition zones**	·	●		○	·	○	○
Food & Biomass Production	*NBS_tu*	(44) **Aquaculture**		○			●	○	●
		(45) **Hydroponic and soilless technologies**	○	○			●	○	●
		(46) **Organoponic/Bioponic**	○	○	●		●	○	●
		(47) **Aquaponic farming**	○	·			●	○	●
		(48) **Photo Bio Reactor**	·	·	●	○	●	●	
	NBS_su	(49) **Productive garden**	●	●	○		●	●	○
		(50) **Urban forest**	●	○			●	●	●
		(51) **Urban farms and orchards**	●	●	●		●	○	●

The NBS global score for all NBS_u/i is shown in Figure 4. All NBS_u/i scores ranged between 0.05 and 0.80. Such an "extreme" range indicates that some NBS_u/i might be very generally applicable and address multiple UCCs, while other NBS_u/i might be more specific and address only a small number of UCCs. In this sense, approximately 40% of all NBS_u/i scored higher than 0.5, thus demonstrating good overall performance in addressing several UCC. The majority of NBS_u/i from "Food and biomass production" and "Vertical greening systems and green roofs" revealed high scores, varying from 0.57 to 0.81, showing that these NBS_u/i tend to be more versatile and generalist (address well multiple UCCs). Whereas NBS_u/i from "(River) Restoration", "Soil and Water Bioengineering" to "Rainwater management" might be better suited for addressing specific UCCs, since the majority of NBS_u/i from these sub-categories had low scores, varying between 0.05 and 0.33. In fact, as expected, all NBS from these subcategories scored for water related UCC_1 and UCC_2. It should be noted that no NBS_u/i from these sub-categories addressed all seven UCCs, and only eight NBS_u/i (out of 21) addressed more than four UCCs.

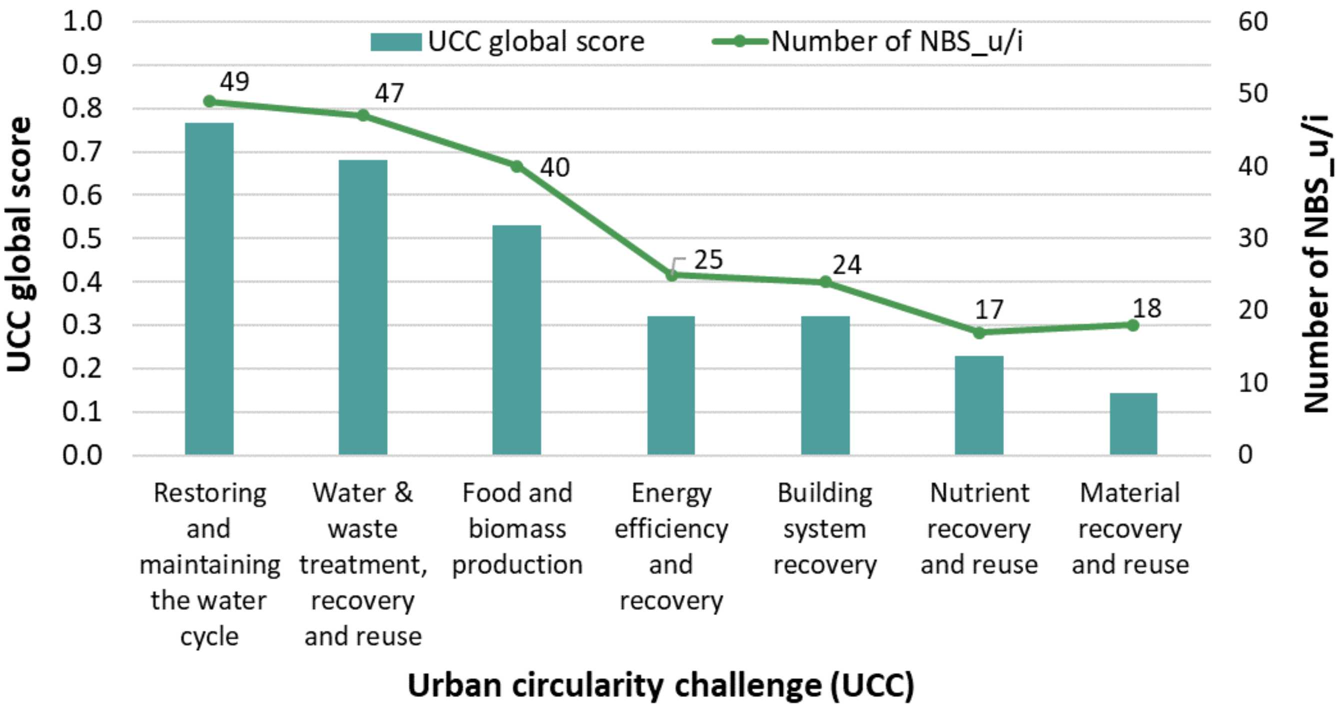

Figure 3. Performance of NSB_u/i in addressing Urban Circularity Challenges.

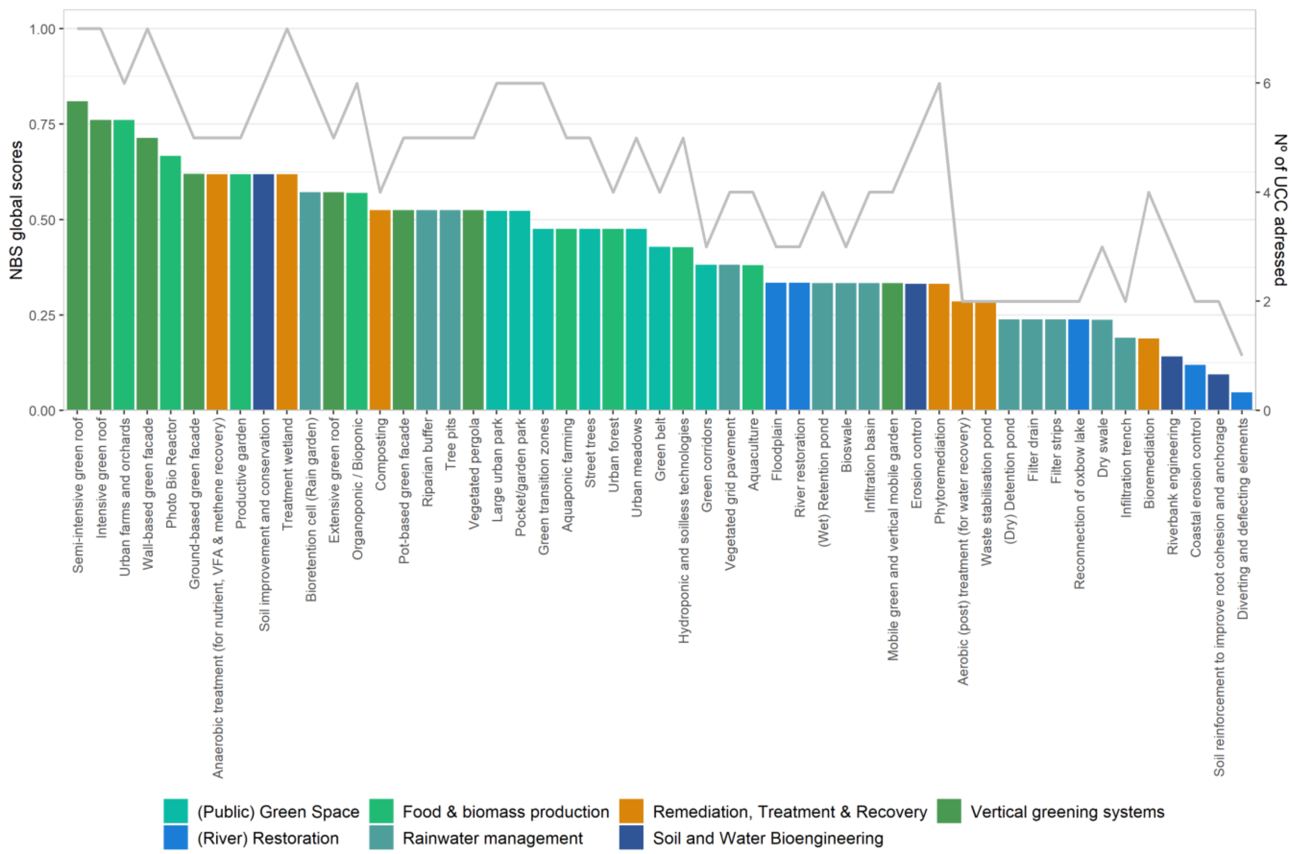

Figure 4. NBS global scores for UCC (colored bars) and number of UCC addressed per each NBS_u/i (gray line). Obs: The bars are colored as a function of pre-established sub-categories.

3.3. Nature-Based Solutions' (NBS) Circularity: An Analysis of Inputs (I) and Outputs (O)

In this article, Inputs (I) required for operation and maintenance of NBS_u/i and S_u and potential Outputs (O) produced by NBS_u/i and S_u are considered as streams (elements and resources flowing through NBS). As inputs, these streams are required for the operation and maintenance of NBS, and thus, they can come from or be produced by other NBS or from other parts of the urban system. As outputs, the streams present resources to be recovered and provided for holistically operating NBS in circular cities, and thus, they are essentially produced by NBS and can flow to other NBS or to other parts of the urban production chain. In the course of the elicitation workshops, five streams were identified (water, nutrients, biomass, living organisms, and energy), comprising over 20 categories (Figure 5).

Figure 5. Main types of streams and respective categories of inputs required for the operation and maintenance of NBS and/or outputs potentially produced by NBS in circular cities.

Understanding the role of NBS in optimizing the flow of different streams is a very important step to promote their implementation for circular cities. However, an equally important aspect is the potential interactions between streams that can be expedited through the implementation of NBS in cities. Streams and their respective categories as shown in Figure 5 are described below:

- *Water:* NBS can play an important role in establishing a more efficient and more circular management of water streams in urban settlements. Moreover, all plant-based systems, such as NBS, rely on a sufficient water supply to permit their full multifunctional properties. The stream categorisation is based on the main elements of urban water management. Precipitation and surface runoff are key categories in urban water management. Precipitation can be directly used as an input without the need for human interference and should be considered for assessing potential hydric deficits that may need to be compensated by other water streams. Surface runoff is generated by precipitation falling onto sealed areas (e.g., roofs, streets) and thus requires retention, transportation, treatment, and storage for reuse. However, the management of surface runoff using NBS [23] follows the conventions of urban drainage where the primary focus lies in removing water from the city as quickly as possible. This way of thinking needs to be reformed by CE concepts to foster a culture of reuse. Wastewater is a valuable but often overlooked water stream. While wastewater in the urban environment is mainly thought of as originating from domestic or industrial activities, specific NBS can also be a source of wastewater (i.e., aquaculture or urban farms), meaning this category can be represented as either an input or an output. The main concerns surrounding the flow of wastewater streams in the urban context are the potential health risks related to reuse practices as well as bureaucratic burdens (i.e., permissions), a lack of common agreement regarding reuse standards required for various different final uses, and structural requirements for practices such as source separation (graywater and blackwater). Even though these concerns are valid, scientific research has demonstrated that the collection of graywater followed by on-site treatment using NBS can present a valuable source of non-potable water [28].

- *Nutrients:* Nutrients can be categorized as solid, liquid, or gaseous. Their management is linked to managing water and biomass streams. The recovery of nutrients from the wastewater stream also promotes the practice of decentralized source separation. While graywater plays an important role in ensuring sufficient water quantity, black water presents a source of nutrients for various uses [29]. An important factor for the recovery of specific nutrients is the S_u in Table A2. An often overlooked fact is the introduction of nutrients via the atmosphere [30].
- *Biomass and living organisms:* Biomass and living organisms are streams related to NBS_u/i associated with urban agriculture and the establishment of an interconnected, sustainable urban food system. Biomass includes categories such as organic fertilizer (compost, manure), organic crop protection products, soil conditioners (mulch, woodchips, or biochar), and a wide range of organic wastes (food waste, crop residues, or pruning remains). Living organisms are the backbone of urban agriculture because they are either prerequisites for food production or constitute food themselves, from plants to vertebrates and microorganisms. Biomass and living organisms can be inputs as well as outputs of various NBS_u/i for urban agriculture and thus have high potential to contribute to circularity in the city. Parts of both streams cross the circular city system boundary, for agriculture and aquaculture are sectors where economies of scale are significant and often cannot be fully exploited by NBS_u/i for urban agriculture due to space constraints in cities. Another reason for this is the need for an external NBS_u/i due to specialization, e.g., the need for fish hatchery rearing fingerlings used in urban aquaponics.
- *Energy:* Energy production and energy savings are key aspects of NBS. While the shading, cooling, and insulation effects can lower the energy demand of a building, source separation, as discussed with the water stream, can provide energy in the form of biogas. Heat exchange from graywater or wastewater has also been identified as an important potential source of energy in circular economies.

To illustrate the interaction of streams, one can analyze the potential of building integrated NBS_u, namely green roofs and pot-based green facades. At the building scale, source separation is generally applicable. By using a two-pipe system, graywater (wastewater without toilet waste) can be captured, and its heat energy can be extracted by heat exchange technology. For water reuse, either green roofs or pot-based green facades can act as treatment units [28]. The supplied water for treatment also acts as a driver for transpiration cooling by the plants. Treated graywater can be used further for irrigation, toilet flushing, and other applications. The wastewater from the toilet can be treated on-site by using S_u, namely an anaerobic reactor producing nutrient-rich effluent and biogas while also eliminating pathogens and rendering water fit for reuse. Further treatment of the effluent is possible by green roof or pot-based facade systems, which themselves support cooling, biodiversity, and biomass production when harvested, and, as previously discussed, have a high energy-saving potential.

4. Conclusions

The following can be concluded:

- The unique list of thirty-nine NBS units, twelve NBS interventions, and ten Supporting units was specifically developed for addressing the Urban Circularity Challenges (UCCs).
- The list of NBS units and interventions (NBS_u/i) is presented in a concise way including categorization, clear nomenclature, and descriptions.
- By including the series of workshops within the COST Action Circular City, the list of NBS_u/i was developed in an interdisciplinary setting intended to facilitate their widespread application.

- The sub-categories applied in the grouping of NBS_u/i according to their main application/role allow for easy understanding and application of the list.
- The framework model combining NBS_u/i with UCCs, with versatile urban sectoral applications, enables the promotion and implementation of innovative plans of action with inclusive and relevant urban regeneration solutions, understanding urban demands as transformative target opportunities toward a resource-efficient and holistic growth model.
- It is noteworthy that the majority of NBS_u/i and S_u from the compiled list are able to fully address the challenges related to the water cycle restoration and maintenance (UCC_1), as well as the treatment, recovery, and reuse of water and waste in cities (UCC_2). In contrast, the current ability of NBS to address the recovery and reuse of nutrients (UCC_3) and materials (UCC_4) in urban areas is still limited (according to the involved experts' knowledge and experience) and requires further research.
- The systematic methodology applied for defining input and output streams facilitates the integration of NBS_u/i into circular solutions and fosters circular thinking.

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Appendix A

Table A1. Descriptions of Urban Circularity Challenges.

Urban Circularity Challenge	Description
UCC_1—"Restoring and maintaining the water cycle"	UCC_1 relates to the water cycle and, more specifically, includes the objective of restoring the natural, pre-development water cycle (mainly by rainwater management). This refers to the behavior of water entering the urban system as precipitation, and the proportions that respectively contribute to evapotranspiration, infiltration, runoff, and other hydrological processes that characterize the water balance. Greening of the urban environment, reducing the proportion of impervious surfaces, rainwater harvesting, and preserving soil and wetlands for water storage all contribute to slowing the passage of water throughout the catchment and help to re-establish a near pre-development water balance. By implementing NBS throughout urban areas, it creates a web of dispersed facilities for onsite stormwater management and runoff control through temporal storage, infiltration, and groundwater recharge. In this context, protection against floods and drought constitutes the central benefits relating to the other challenges [31–33]. The NBS that address this challenge include various infiltration options such as retention ponds, green roofs, rain gardens, and floodplains.

Table A1. *Cont.*

Urban Circularity Challenge	Description
UCC_2—"Water and waste treatment, recovery, and reuse"	UCC_2 embraces topics and potential issues to be addressed by NBS in the scope of water and wastewater treatment, recovery, and reuse. The treatment of wastewater removes pollutants that can be damaging to the environment and sensitive ecosystems as well as pose health risks to urban dwellers. Instead of conventional practices of collecting all streams of used water in underground pipes and conveying it to a centralized wastewater treatment plant, circularity involves more differentiated management of the various wastewater streams from industry and households. The wastewater streams (i.e., gray, yellow, brown, black) can be reused in a fit-for-purpose approach, in which the quantity and quality of the water that is to be reused should match the quality requirements of the reuse purpose. NBS central to treatment, recovery, and reuse of water include treatment wetlands, rain gardens, or rain-harvesting systems [34,35].
UCC_3—"Nutrient recovery and reuse"	UCC_3 focuses on the recovery and reuse of nitrogen (N), phosphorus (P), and potassium (K), which are valuable resources that enter household wastewater through human excreta. Removal of these components from wastewater not only ensures a safer reintroduction into the natural environment, but these components also serve as a resource in fertilizer production, which can be utilized in urban agriculture or landscaping. The separation of different substance streams is an efficient way to recover nutrients such as N and P, but this practice requires substantial changes in the way we manage human waste. Substantial changes to infrastructure at both household and city level are needed for the source separation approach. Nutrients recovered from wastewater streams and source separation can be used in gardening and food production as a circular alternative to artificial fertilizers. Struvite fertilizer is an example of nutrient recovery for food production [29,36]. Using the nutrients from wastewater is not a new concept, but the systematic implementation of such practices and adjusting city planning accordingly is. The NBS central to nutrient recovery and reuse include treatment wetlands, waste stabilization ponds, composting, bioremediation, and phytoremediation.
UCC_4—"Material recovery and reuse"	UCC_4 embraces topics related to material recovery and reuse, and it pertains to the resources needed in the built environment. The concept of an urban mine relates to the idea that there is already an abundance of materials present in the urban environment that can be repurposed, recycled, and reused instead of relying on primary resources imported from outside the city. Extending this concept to NBS, some of the urban greening measures such as urban parks and urban meadows can provide biomass for various uses, such as insulating material or other bio-based materials used in construction and manufacturing processes. Biochar production was identified as a supporting NBS_u in the Circular City repository that can supply a high-energy, renewable energy source from plant material.
UCC_5—"Food and biomass production"	**UCC_5** relates to the crucial matter of sustainable food and biomass production in cities. Since there is no food production without water, the many intersections between urban water and urban agriculture are clear as well as the intrinsic link between UCC_5 and water-related $UCC_{1,2}$. For example, NBS such as hydroponic systems are generally more efficient than traditional soil-based systems in terms of water use and can be as productive as the latter. In addition, various types of water sources (from tap water to wastewater) can be collected and recirculated within the hydroponic system. Noteworthy NBS used in urban agriculture are ground-based and rooftop gardens, edible walls, hydroponic food production (indoor and outdoor), as well as urban orchards, honey production, and aquaculture. However, NBS with different purposes (beyond food production) can interact in order to address UCC_5 and other linked $UCC_{1,2,3}$. For example, treatment wetlands (TWs) used for water pollution control can contribute to a community garden through the provision of treated wastewater for irrigation and the production of compost or peat, which can be used for conditioning soils, boosting soil fertility, increasing water storage capacity, and improving productivity [37].
UCC_6—"Energy efficiency and recovery"	Reducing the demand for imported (fossil fuel-based) energy is the main challenge from a CE viewpoint related to energy. Energy-efficient buildings, mitigation of the urban heat island effect—and consequently, reducing the demand for cooling in buildings—and heat and energy recovery from different waste streams are foreseen goals that can be achieved with NBS in a circular concept [14].
UCC_7—"Building system recovery"	UCC_7 relates to the topic of regeneration of the built environment, i.e., architecture and infrastructure for living, working, manufacturing, and developing other activities. The construction materials and building systems are exposed to less weathering, such as snow, rain, wind, and extreme temperatures. Buildings and open spaces are shaded from UV radiation and pollutants, which increases the lifespan of most common building materials and reduces the rate at which renovations or the replacement of infrastructure have to take place [38]. In turn, this can save resources that often rely heavily on the use of fossil fuels and other non-renewable resources. Greening the open space and implementing water-sensitive urban design are equally key strategies, aimed at providing ecosystem services related to water, such as stormwater management, and on-site water reuse, as well as, indirectly, urban heat island mitigation.

Table A2. Descriptions and synonyms/subgroups of NBS units (NBS_u), NBS interventions (NBS_i), and Supporting units (S_u) from Table 1.

#	Units/Interventions	Synonyms/Subgroups	Descriptions
1	**Infiltration basin**	Green water storage and infiltration system; Storm basin; Non-permanent infiltration basin; Green water storage and infiltration system; Storm basin; Micro-catchment; The sponge zone [15]	An **infiltration basin** is a surface storage basin designed for short-term temporal water storage by using an existing natural depression in the ground or by creating a new one. After a heavy rain, the water fills up the depression. Then, the water soaks into the ground or drains to the sewage system. If there is no heavy rainfall, the area is dry and could be used as a green area. Adapted from [15].
2	**Infiltration trench**	Percolation trench	**Infiltration trenches** are laminated systems with fabric-lined excavations atop a fabric-lined reservoir to increase infiltration. Adapted from [39].
3	**Filter strips**	Vegetative filter strips	A **filter strip** is a sloped medium that attenuates stormwater runoff by converting it into sheet flow and is typically located parallel to an impervious surface such as a parking lot, driveway, or roadway. Furthermore, the adoption of vegetated filter strips is increasing as they have been demonstrated to be effective for trapping runoff and sediment and promoting soil infiltration. Adapted from [39,40].
4	**Filter drain**	Filter trench; Surface sand filter	**Filter drains** are shallow trenches filled with stone/gravel that create temporary subsurface storage for attenuation, conveyance, and filtration of surface water runoff. The stone may be contained in a simple trench lined with a geotextile, geomembrane, or other impermeable liner, or with a more structural facility such as a concrete trough. Adapted from [41].
5	**(Wet) Retention pond**	(Wet) Retention basin; Wet pond; Wet pool; Water retention ponds; Green retention pond; Extended Retention Basin; Holding pond; Pond; (Wet) retention basin [15]	**(Wet) Retention ponds** consist of a permanent lagoon area with landscaped banks and surroundings to provide additional storage capacity during rainfall events. It has the capacity to continuously retain storm water, remove urban pollutants, and improve the quality of both surface runoff and release this at a controlled rate. During dry periods it also holds water. Adapted from [15].
6	**(Dry) Detention pond**	(Dry) Detention basin; Dry ponds	**Detention ponds**, or dry ponds, are stormwater basins designed to intercept stormwater runoff for temporary impoundment and metered discharge to a conveyance system or a receiving waterbody. In this regard, it can contribute to the prevention of urban flash flooding. Adapted from [39].
7	**Bioretention cell**	Bioretention facility; Rain garden; Pluvial beds; Biofilter; Infiltration/stormwater planters; Infiltration garden; Rainfall garden; Water control garden, Floodable garden, Bioretention filter, Bioretention area, Bioremediation wet retention [15]	A **bioretention cell** is a shallow depressed vegetated area that primarily serves as a small-scale water control (storage and infiltration) area, especially in cities. It is designed to collect, store, filter, and treat water runoff. Storm water runoff is drained, stored for a certain period, and then, it infiltrates either into the ground soil or flows into the sewage system. To optimize its functions, it must include a porous soil mixture, native vegetation, and some hyper accumulator plants, which are capable of phytoremediation. Adapted from [15].

Table A2. *Cont.*

#	Units/Interventions	Synonyms/Subgroups	Descriptions
8	**Bioswale**	Swale; Green drainage corridor; Vegetative filter; Vegetated bioswale [15]	A **bioswale** is a vegetated, linear, and low-sloped shallow pit or channel, often established in urban areas. It is designed to store and convey surface water runoff and also to remove pollutants and sediments. Furthermore, vegetation can intercept rainfall, increase subsurface water storage capacity, and improve infiltration. This NBS is often used to drain roads, paths, or car parks while enhancing access corridors or other open space. Adapted from [15,42].
9	**Dry swale**	Grassed swale	A **dry swale**, or grassed swale, is an open vegetated conveyance channel that filters, attenuates, and detains stormwater runoff as it moves downstream. Vegetation can include turf, meadow grasses, shrubs, and small trees (in limited quantities). Furthermore, the water flow through the swale can be slowed by a series of check dams. Adapted from [39,43].
10	**Tree pits**	Planters; Tree box; Tree pit filter	**Trees pits** and planters can be designed to collect and attenuate runoff by providing additional storage within the underlying structure. The soils around trees can also be used to directly filter out pollutant from runoff. (SUDS Manual). A tree box filter or in-ground well consists of a container filled with amended soil and planted with a tree, which is underlain by crushed gravel media. Tree pits are attractive for stormwater control in dense urban areas because of their small size, low cost, and associated co-benefits that they bring by greening the streets. Adapted from [39,41,44].
11	**Vegetated grid pavement**	Permeable/pervious/infiltration pavements; Green/greened/vegetated/grass pavements; Green parking pavements; Engineered vegetated green pavement; Grass block paver/interlocking grass paver; Permeable pavements and parking lots; Pervious surfacing; Permeable green pavements [15]	A **vegetated grid pavement** includes planted pavement structures normally filled with soil, grass seeds, gravel, or rocks. It can be considered as a type of pervious/permeable pavement. The runoff soaks through the pavement structure and can be stored or infiltrated into the ground. Accordingly, using permeable pavement is appropriate for decreasing the urban flooding problem and urban heat island effect. The structures are modular and adaptable to different surface types such as parking areas, roadways, cycle–pedestrian paths, sidewalks, or street furniture zones. Usually, the costs and maintenance are low compared to traditional pavements. Adapted from [15,45].
12	**Riparian buffer**	Riparian buffer strip; Vegetative filter strips; Buffer strips	A **riparian buffer** reduces surface runoff and detains sediments and sediment-bound pollutants from (mainly) agricultural areas. Located between agricultural catchments and streams/rivers, they act as filters for pollutants and sediment transportation into the river, slowing down the flow. They comprise hydric soil with facultative vegetation along the banks of a river or stream offering niche ecotone services. Riparian buffers provide a series of ecosystem services and functions such as reservoirs of biodiversity, flood mitigation, wetland products, bank protection, recreation, and water purification. Adapted from [39,46].

Table A2. *Cont.*

#	Units/Interventions	Synonyms/Subgroups	Descriptions
13	**Ground-based green facade**	*Green facade*; Green facade with climbing plants; Climber green wall; Ground-based green-wall; Green climber wall; Green wall with ground-based greening; Climber plant wall; Ground-based green facade with climbing plants; Soil-based green façade [15]	A **ground-based green facade** is a wall completely or partially covered with greenery. The climber plants are planted in the ground (soil, technical, or recycling substrates) or in containers (filled with soil) and grow directly on the wall, or climb using climbing-aids (e.g., on a frame) that is connected to the wall. These NBS can also be implemented along highly frequented roads to reduce noise emissions. Adapted from [15].
14	**Wall-based green facade**	*Green wall;* Hydroponic green facade; Facade-bound greening; Facade bound green wall; Living wall; Continuous green wall; Plant wall system; Green façade with vertical panels; Greening vertical panel; Vertical greening panel [15]	A **wall-based green facade** (or green wall) comprises panels and technical structures (3D frames filled with technical substrate) that are seeded or planted. These panels and structures are fixed onto facades or walls or can be designed as stand-alone system and allow the placement of plants and substrate on the entire surface. Some systems allow the removal of panels during winter time. Compared to soil/ground-based green facades a wider plant range can be applied for wall-based green facades. Adapted from [15].
15	**Pot-based green facade**	Living wall; Planter green wall; Planter green facade; Planter boxes; Planter pots; Planter-based green wall; Planted/planting container(s); Pot planted plants; Potted plants; Potted mobile garden; Raised bed; Container plants [15]	A **pot-based green facade** involves the use of planted containers such as pots or planters, filled with artificial (technical) soilless substrate or soil or a mixture. They can be placed on the ground or directly on the building or balconies. They can be used with almost any kind of plants, e.g., climbing plants, trees, and/or shrubs. Adapted from [15].
16	**Vegetated pergola**	Green pergola; Greened pergola; Green mattresses; Green shady structures; Green shade [15]	A **vegetated pergola** uses pillars, beams, stretched textile structure, and lattices in different materials and compositions to create a growing assistance for vegetation and provide shaded areas. On this structure, an inert substrate can be installed, to be covered with seeds. Vegetated pergolas can be fixed to the facades of the buildings, on the street, or by posts fixed to the sidewalk. Adapted from [15].
17	**Extensive green roof**	Green roof; Vegetated roof; Living roof [15]	An **extensive green roof** implies basic, light-weight, planted systems that are implemented on the rooftop of a building. The most common plants used are sedum, herbs, mosses, and grasses. The installation and maintenance are less expensive than that of intensive systems. The substrate is relatively thinner (10–15 cm, or reduced form >10 cm) than for intensive systems (more than 20 cm). Adapted from [15].
18	**Intensive green roof**	Green roof; Roof garden; Roof park; Vegetated roof; Living roof; Public intensive green roof; Social intensive green roof [15]	An **intensive green roof** consists of vegetation (higher variety than extensive green roof) that are installed on rooftops, normally accessible for public or recreation or gardening, relaxation, and socialization purposes. This NBS is usually heavier and has a deeper substrate (more than 20 cm) as compared to extensive systems. In addition, it requires more installation and maintenance effort such as regular irrigation and fertilization, but it provides more biotopes and higher biodiversity. Adapted from [15].

Table A2. *Cont.*

#	Units/Interventions	Synonyms/Subgroups	Descriptions
19	**Semi-intensive green roof**	Green roof; Smart roof; Vegetated roof; Living roof; Biodiversity roof; Eco systemic roof [15]	A **semi-intensive green roof** is a combination of areas as intensive and extensive green roof. It is implemented on rooftops and is characterized by small herbaceous plants, ground covers, grasses, perennials and small shrubs, as well as higher growing plants, requiring moderate maintenance. The recommended minimum substrate thickness is between 12 cm (grass or herbaceous plants) and 20 cm (smaller shrubs and coppices), but it can be adjusted. This type of green roof has higher maintenance than extensive systems and has the potential to host a richer ecology. Adapted from [15,47].
20	**Mobile green and vertical mobile garden**	Mobile vertical greening; Mobile green living room; Mobile green wall; Mobile vertical garden; Portable green wall; Mobile planter [15]	These NBS units are mobile and thus can be located anywhere in the city. A **mobile green** is usually organized as greened or planted containers or pots that are removable. All plant types can be used for this NBS. For trees, large-scale containers are required. A **vertical mobile garden** is a vertical, mobile, planted, self-supporting module. It is fixed to a hook lift container platform. On this structure, different layers are placed along a substrate (also hydroponic can be used) in which the plants can grow. Adapted from [15].
21	**Treatment wetland**	Constructed wetland; Reed bed; Planted horizontal/vertical filters; Helophyte filter; Root-zone wastewater treatment; Natural wastewater treatment; Artificial wetland; Planted sand/soil filters [15]	**Treatment wetlands (TWs)** include a range of engineered systems designed and constructed to replicate natural processes occurring in natural wetlands involving vegetation, soils, and the associated microbial assemblages to assist in treating wastewater streams (e.g., domestic wastewater, graywater, industrial wastewater) and stormwater. TWs can be divided in two main hydrological categories: **Free water surface wetlands**, a shallow sealed basin or sequence of basins (open water areas) containing floating plants, submerged plants, or emergent plants (similar in appearance to natural marshes); Subsurface flow wetlands, which include **Horizontal flow (HF) wetlands** and **Vertical flow (VF) wetlands**. In this case, the water flows beneath the surface level, either horizontally or vertically, through the filter bed. Adapted from [15,48].
22	**Waste stabilization pond**	Wastewater pond	**Waste stabilization ponds (WSPs)** are earthen ponds designed and constructed in series, where sequential microbial metabolisms (anaerobic + facultative + aerobic) are established. WSPs utilize both physical and biological processes to remove organic materials, pollutants, and pathogens in raw wastewater. The size of the infrastructure can be comparable to a treatment wetland unit in some cases, and it can be applied also for cities. Adapted from [49,50].
23	**Composting**	Community composting; Compost heap; Composting facility [15]	**Composting** includes all the structures and procedures required to compost food waste, vegetable materials, waste from cleaning grain, crop residues, etc. Adapted from [15].

Table A2. *Cont.*

#	Units/Interventions	Synonyms/Subgroups	Descriptions
24	**Bioremediation**		**Bioremediation** refers to bacteria- and fungi-based techniques to remediate contaminated soil and groundwater while simultaneously improving soil quality and providing ecosystem services. Bioremediation approaches can be applied in situ or ex situ, which depends on the nature of contaminant and site conditions. Adapted from [51,52].
25	**Phytoremediation**		**Phytoremediation** refers to plant-based techniques to remediate contaminated soil and groundwater while simultaneously improving soil quality and providing ecosystem services. Phytoremediation is a cost effective, non-intrusive, and aesthetically pleasing technology that removes contaminants by applying processes and mechanisms of degradation, sequestration, or transformation. Adapted from [53,54].
26	**Anaerobic treatment** (for nutrient, VFA, and methane recovery)		**Anaerobic treatment** refers to a treatment technology that stabilizes organic wastes or organic pollutants in wastewater, without the need for aeration. During anaerobic treatment, biodegradable organic compounds are mineralized, leaving inorganic compounds such as NH4+, PO43-, HS- in the solution. Anaerobic treatment can be conducted in technically plain systems, and the process can be applied at any scale and at almost any place. During treatment, useful energy in the form of biogas (CH_4 and CO_2) or chemical building blocks such as volatile fatty acids (VFA) are produced. Adapted from [55].
27	**Aerobic (post) treatment** (for water recovery)		**Aerobic treatment** refers to the removal of pollutant under the presence of dissolved oxygen. In aerobic biological oxidation reactors, the conversion of organic matter is carried out by mixed bacterial cultures in general accordance with the following stoichiometry: COHNS + O_2 + nutrients$\rightarrow$ CO_2 + NH_3 + $C_5H_7NO_2$ (new cells) + other end products. Examples of aerobic reactors are activated sludge and biofilm reactors. Aerobic autotrophic bacteria are responsible for nitrification (conversion of ammonium to nitrate) in these reactors. Adapted from [56].
28	**River restoration**	River re-naturing; River revitalization; Blue corridors; Soil-bioengineering for river re-naturing; River restoration; River revitalization; Daylighting; Reopened stream; Channel widening and length extension; Reprofiling the channel cross-section; Channel reprofiling and re-opening; Fluvial restoration/rehabilitation; Deculverting and re-meandering [15]	**River restoration** includes a set of techniques that aim to reduce pluvial flood risk and erosion. The river channel is widened or deepened, recovering part of its former channel, and enhancing the flood dissipation capacity. In case of covered/buried watercourses, the channel can be opened by removing concrete layers. Both ways lead to an increment of storage capacity of the channel and natural development of the riverbed and riparian zone. Adapted from [15].

Table A2. *Cont.*

#	Units/Interventions	Synonyms/Subgroups	Descriptions
29	**Floodplain**	Reprofiling/extending floodplain; Branches; Floodplain restoration; Floodplain widening; Restore/increase the floodplain area; Room-for-the-river approach/Floodplain management [15]	**Floodplains** aim to reduce flood risk by expanding the flood plain/water retention, thus providing additional flood space. Floodplain can be restored by excavating the lateral riverbed or by dividing the discharge into branches and by-passes, creating islands. During low water levels, these relatively flat and accessible bank areas can be used for multifunctional purposes. Floodplain restoration enables more efficient work of sewer and storm water pipe drainage systems by reducing their operational load and decreasing the need for expensive pipe solutions. Adapted from [15,57].
30	**Diverting and deflecting elements**	Natural flow diversion structures; Redirection of water flow, Stimulation of river dynamic processes; Instream structures; (Soil and) water bioengineering for stream restoration; Water bioengineering flow changing techniques; Riverbed morphology engineering; Increased water course friction [15]	**Diverting and deflecting elements** employ elements such as rocks, larger tree trunks, and willow branches that are placed near the riverbank or in the middle of a river. These interventions alter flow variation and sediment shifting processes, affecting the development of the channel's length and depth. In this sense, the main objective is to redirect, disturb, divert, and deflect the water flow and initiate water dynamics for riverside protection against erosion. Adapted from [15].
31	**Reconnection of oxbow lake**		An oxbow lake is an ancient meander that was cut off from the river, thus creating a small lake with a U-form. **Reconnecting oxbow lake** with the river consists in removing terrestrial lands between both water bodies, therefore favoring the overall functioning of the river by restoring lateral connectivity, diversifying flows, and cleaning the river section of the present oxbow for a better water retention during floods. The reconnection of oxbow lakes is also important for improving the diversity of riverine species. Adapted from [58].
32	**Coastal erosion control**		**Coastal erosion control** summarizes a set of techniques that aim to reduce coastal erosion by reducing wave velocity and trapping sediments. These technologies include coastal wetlands, salt marshes, large woody debris, coral and oyster reef systems, semi-permeable and permeable dams, etc. and techniques for sand dune restoration. Adapted from [59,60].
33	**Soil improvement and conservation**	Soil enhancement; Soil amendment; Soil improvement and conservation measures; Soil enhancement(s); Gentle remediation options; Soil management; Engineered, improved soil [15]	**Soil improvement and conservation** comprise several approaches to maintain and enhance soil quality in terms of physical, chemical, and biological features. It aims to improve nutrient management, increase carbon storage, enhance water infiltration and retention, encourage beneficial soil organisms and prevent soil compaction. Some examples of specific techniques are application of biochar, mulching, use of leguminous species for enhancing nitrogen fixation, use of organic matter, retaining stubble and green manuring to increase organic content and reduce compaction and erosion, and organic fertilizer that stimulate and increase the soil biological activity and diversity. Adapted from [15].

Table A2. *Cont.*

#	Units/Interventions	Synonyms/Subgroups	Descriptions
34	**Erosion control**	Soil bioengineering (slope); Soil (and water) bioengineering for slope stabilization and erosion control; Soil and slope revegetation; Strong slope vegetation; Slope vegetation/revegetation; Slope stabilization through revegetation; Soil and slope stabilization; Vegetation engineering systems for slope erosion control [15]	**Erosion control** includes a set of different soil bioengineering techniques to stabilize soil structure on steepened slopes, to minimize/prevent the erosion of soil from wind or water, landslides, and sedimentation problems. Common techniques are: revegetation (plants with strong deep roots), hydro-seeding, erosion control mat, covering natural fiber mats, wooden structures, and surface roughening. Adapted from [15].
35	**Soil reinforcement to improve root cohesion and anchorage**		**Soil reinforcement to improve root cohesion and anchorage** is induced by using live plant material for engineering purposes: woody plants and parts of plants (branches or stems) are placed in a constructive manner and according to defined design principles, e.g., brush layering, branch packing, live staking, fascine constructions. Furthermore, it is possible to use the construction waste for the reinforcement of soft soil foundation in coastal cities. This approach can decrease the cost of garbage removal and transportation, reduce the cost of foundation reinforcement, and also reduce the land occupation by waste. Adapted [61,62].
36	**Riverbank engineering**	Riverbank engineering; Vegetation engineering systems for riverbank erosion control; Bioengineering (soil, water, fluvial, riverbanks); Riverbank stabilization/slope stabilization; Vegetated bank protection; Systems for erosion control on riverbanks; Riverbank protection system [15]	**Riverbank engineering** techniques are used in fluvial bioengineering for riverbank protection and hillside stabilization to reduce the risk of erosion by generating a natural protection. Some techniques embraced are as follows: planted embankment mat; plants established on hills with strong inclination to provide strong and branched root networks; engineered designs using plant material and woody plant parts (e.g., fascine constructions, willow branch mattress); living and dead wood can be combined (e.g., vegetated crib walls, dead and live wood branch packing) for linear application and wide-spread effects; live stakes and other plant elements can be used jointly or individually to stabilize the slope (live stakes, root stocks, fascine brushes, etc.). Adapted from [15].
37	**Green corridors**	Green way [15]	**Green corridors** aim to renature areas of derelict infrastructure such as railway lines or along waterways and rivers, transforming them into linear parks. This NBS can be considered as a transitional area between biomes that connect neighborhoods. Green corridors can play an important role in urban green infrastructure networks and can offer niche shelter, food, and protection for the urban wildlife to survive and move from one green space patch to another. Adapted from [15].
38	**Green belt**	Green bypass	A **green belt** is a green area surrounding built-up area. It is a planning device designed to contain urban growth that is established for dividing urban and rural areas, and it has the function of supressing urban sprawl and providing recreational areas for residents. Adapted from [63,64].

Table A2. *Cont.*

#	Units/Interventions	Synonyms/Subgroups	Descriptions
39	**Street trees**	Allée; urban trees; Trees on streets; Tree infrastructure; Planting and renewing urban trees; Boulevards; Urban tree canopy; Tree infrastructure; Urban trees alignment; Single line trees; Sustainable management of urban trees; Single tree [15]	**Street trees** are focused on planting, renewing, or maintaining urban street trees. It is designed to be appropriate for its context (right tree in the right place) and to achieve multiple benefits. One single or several trees can be arranged along streets, bicycle paths, and sidewalks. These trees are situated on a single side (e.g., single line trees), and if circumstances allow, they can be established on both sides of the route (e.g., boulevard). In the latter case, the treetops of opposite trees often form a (nearly) closed canopy. Street trees support healthy urban communities through the provision of environmental, social, and economic benefits. They improve cities' liveability through the provision of shade, stormwater reduction, improved air quality, and habitat connectivity for urban fauna. Social benefits are represented by the sense of community and safety, and reduced rates of crime. Regarding economic benefits, street trees can reduce energy costs and also increase the business income and property values Adapted from [15].
40	**Large urban park**	Urban park; Public park; Park; Green park; Residential park; City park; Large urban public park; Greened recreation areas/regional parks; Green resting areas; City park [15] and [65]	**Large urban parks** refers to large green areas (>0.5 ha) within a city with a variety of active and passive recreational facilities that meet the recreational and social needs of the residents and of visitors to the city. They are open to wide-range communities. Large urban parks can serve all the city or part of city, and they are open to a wide range of communities. Adapted from [15].
41	**Pocket/garden park**	Small park; Neighborhood park; Landscape park; Empowerment park; Pocket parks [15] and [65]	**Pocket or garden parks** are publicly accessible and compact green areas or small gardens (<0.5 ha) around and between buildings vegetated by ornamental trees, grass, and other types of plants. The area is projected for resting, relaxation, observing nature, social contact, and physical health. Pocket or garden parks provide opportunities for people to create small but important public spaces left in their own neighbourhoods. Adapted from [15].
42	**Urban meadows**	Urban wildflower meadows	**Urban meadows** are species-rich grasslands created over a longer period of time, which are beneficial to native wildlife in the urban environment. The type of meadow created and method used to create and manage them will vary with conditions, habitat, and budget. The benefits of implementing urban meadows (instead of mown grass in urban public green spaces) are evident for urban biodiversity, human wellbeing, and for local economy as a cost-effective solution. Adapted from [66].

Table A2. *Cont.*

#	Units/Interventions	Synonyms/Subgroups	Descriptions
43	**Green transition zones**		**Green transition zones** are between high vegetation (urban forests and parks mainly) and adjacent areas or infrastructure and embedded in urban environments, functioning as enriching spatial units (ecotones) in the landscape, requiring special(ized) management and providing different spaces, including in quality or extent of NBSs in comparison with bordering spaces or ecosystems. Vegetation transitions, or ecotones, represent border regions of transition between communities, ecosystems, or biomes, that reflect both local and regional changes in abiotic conditions. Adapted from [67,68].
44	**Aquaculture**	Flow-through fish farm; Recirculating Aquaculture Systems (RAS)	**Aquaculture** is the farming of aquatic organisms, including fish, molluscs, crustaceans, and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated. Aquaculture includes flow-through fish farms as well as recirculating aquaculture systems (RAS). Aquaculture has potential for providing lower priced fish, enhancing nutritional security and employing poor urban communities. Urban aquaculture can decrease the distance between farm and plate, generate income, use less resources, and serve as a community-building tool. Adapted from [69].
45	**Hydroponic and soilless technologies**		**Hydroponics** is an agricultural method that provides soilless plant growth by applying the mixture of water and nutrient solution that is controllable and can be delivered to plants based on their needs. This system provides improved control of plant's nutrition, efficient use of space, and the possibility of saving fertilizers. Greenhouses with hydroponic systems are seen as sustainable systems for growing food in cities with improved control of plant growth. The huge potential offered by this cultivation approach ranges from productive and qualitative advantages to environmental benefits due to higher efficiency in using water and nutritional resources, $NO3-$ management, and crop quality increase. Adapted from [70–72].
46	**Organoponic/Bioponic**		**Organoponic/bioponic** is an emerging soilless technology for nutrients recovery that links organic vegetable production to organic effluent remediation or organic waste recycling (adapted from [73]). Bioponic production describes a contained and controlled growing system in which plants in growing media derive nutrients from natural animal, plant, and mineral substances that are released by the biological activity of microorganisms [74].

Table A2. *Cont.*

#	Units/Interventions	Synonyms/Subgroups	Descriptions
47	**Aquaponic farming**	Aquaponics; Trans-aquaponics	**Aquaponic farming** comprises aquaponics (which couples tank-based animal aquaculture with hydroponics) as well as trans-aquaponics, which includes integrated aqua–agriculture systems exploiting the aquaponic principle without these restrictions. Adapted from [75]
48	**Photo Bio Reactor**		A **Photo Bio Reactor (PBR)** is defined as a closed (or mostly closed) vessel for phototrophic production in which the energy is supplied via electric lights. A PBR design should use light efficiently with uniform illumination, reduce shading, provide a fast mass transfer of CO_2 and O_2, and attain high biomass growth. Adapted from [76,77].
49	**Productive garden**	Market garden; Community garden; Mobile vertical garden (with substrate or soil)	**Productive gardens** are areas of land dedicated to the cultivation of vegetables, fruits (fruit trees), (flowers), and small livestock (chicken) for the main purpose of food production (whose output has a significant share of food production). These gardens can be differently owned, yet ownership has no effect in terms of the function of the NBS unit. Adapted from [15].
50	**Urban forest**	Group of trees; Wood; Urban woodland; Arboreal areas around urban areas; Arboreal urban parks; Arboretum; Urban tree cover [15]	An **urban forest** mimics the appearance/form of a forest in an urban setting. It comprises all woodlands, groups of trees, and individual trees, forests, street trees, trees in parks and gardens, and trees in derelict corners. Usually, urban forests are managed and enable foraging for food. Benefits of urban forests range from psychological, aesthetic, recreational, and health benefits to amelioration of urban climate, mitigation of air pollution, and increased urban biodiversity. Adapted from [15].
51	**Urban farms and orchards**	Small-scale farms	**Urban farms and orchards** are agriculture ventures dedicated to food production in a city; they are often professionally run and considerably larger than gardens. Food production may include big livestock (cows), fruits (fruit trees), and main food crops (maize, wheat). Larger urban farms also participate in community programmes such as skills development and job training that can benefit underserved populations. Furthermore, as a form of green infrastructure, urban farms and community gardens can help reduce urban heat island effects, mitigate the impacts of urban stormwater, and lower the energy embodied in food transportation. Adapted from [78].
S1	**Rain Water Harvesting**		**Rainwater harvesting** (RWH) in cities consists of the concentration, collection, storage, and treatment of rainwater from rooftops, terraces, courtyards, and other impervious surfaces for on-site use, with the aim of reducing drinking water consumption from centrally supplied sources. Rainwater harvesting reduces runoff volume and peak flows. Rainwater can be collected in cisterns, bladder tanks, and precast ferrocement septic tanks. Adapted from [39,79].

Table A2. *Cont.*

#	Units/Interventions	Synonyms/Subgroups	Descriptions
S2	**Detention vaults and tanks**	Wet vaults; Dry vaults; Attenuation storage tanks	**Detention vaults and tanks** are underground storage/treatment facilities constructed of reinforced concrete (vaults) or corrugated pipe (tanks). They may be used to handle general site runoff, or they may be dedicated to the runoff from impervious surfaces such as roofs and parking lots. Detention vaults may be designed to empty completely between storms (dry vaults), or they may be designed to maintain a permanent water pool (wet vaults). These facilities provide runoff volume control, peak discharge reduction, sediment control, and harvesting potential. Adapted from [39].
S3	**Phosphate precipitation** (for P recovery)		**Phosphate precipitation** refers to the chemical precipitation of phosphorus. It is brought about by the addition of the salts of multivalent metal ions that form precipitates of sparingly soluble phosphates. The multivalent metal ions used most commonly are calcium, aluminum, and iron. For struvite precipitation, magnesium is added. Struvite precipitation is controlled by a combination of physicochemical factors including temperature, mixing energy, pH, the degree of Mg, NH4, and PO4 supersaturation, and the presence of competing ions. Magnesium generally needs to be added. Adapted from [56,80].
S4	**Ammonia stripping** (for N recovery)		Gas stripping (such as dissolved ammonia) involves the mass transfer of a gas from the liquid phase to the gas phase. The transfer is accomplished by contacting the liquid containing the gas (ammonia) that is to be stripped with a gas (usually air) that does not contain the gas initially. For **ammonia stripping**, the ammonia stripped from the wastewater is converted to ammonium by passing the off-gas through an acid bath/scrubber. Adapted from [56].
S5	**Disinfection** (for water recovery)		**Disinfection** describes a process that eliminates pathogenic microorganisms the use of chemical agents (such as chlorine and its compounds), physical agents (such as light, heat, and sound), mechanical means, and radiation. Adapted from [56].
S6	**Biochar/Hydrochar production**		**Biochar** is a carbon-rich solid by-product produced through high-temperature pyrolysis or the degasification of organic material under low or no oxygen environment, which prevents combustion. Biochar is being used in an increasing number of fields and has been widely employed in a variety of applications, such as an adsorbent, a source of nutrients, and soil amendment agent where the biochar amendment could further suppress plant diseases as well. Properties of biochar and its applications are highly influenced by the mode of preparation and type of feedstock used. High moisture-containing feedstocks are converted into biochar (hydrochar) with the help of hydrothermal carbonization (HTC). Adapted from [81].

Table A2. *Cont.*

#	Units/Interventions	Synonyms/Subgroups	Descriptions
S7	**Physical unit operations for solid/liquid separation**		**Physical units for solid/liquid separation** mostly used in wastewater treatment are screening, grit removal, sedimentation, high rate clarification, accelerated gravity separation, (bio-) flocculation, and flotation. Adapted from [56].
S8	**Membrane filtration**		During **membrane filtration,** the role of a membrane is to serve as a selective barrier that will allow the passage of certain constituents and will retain other constituents found in the liquid. Adapted from [56].
S9	**Adsorption**		**Adsorption** is the process is the process of accumulating substances that are in solution on a suitable interface. Activated carbon treatment of wastewater is usually thought of as a polishing step, for example for removing micro-pollutants such as pharmaceuticals, personal care products, and hormones. Adapted from [56].
S10	**Advanced Oxidation Processes (AOP)**		**Advanced oxidation processes (AOP)**, such as ozone treatment, are used to oxidize complex organic constituents found in wastewater; they are difficult to degrade biologically (for example micro-pollutants) into simpler end products. Adapted from [56].

References

1. Hristova, S.; Šešić, M.D.; Duxbury, N. *Culture and Sustainability in European Cities: Imagining Europolis*; Routledge: Oxfordshire, UK, 2015; pp. 1–246. [CrossRef]
2. Akande, A.; Cabral, P.; Gomes, P.; Casteleyn, S. The Lisbon Ranking for Smart Sustainable Cities in Europe. *Sustain. Cities Soc.* **2019**, *44*, 475–487. [CrossRef]
3. Raymond, C.M.; Pam, B.; Breil, M.; Nita, M.R.; Kabisch, N.; de Bel, M.; Enzi, V.; Frantzeskaki, N.; Geneletti, D.; Cardinaletti, M.; et al. *An Impact Evaluation Framework to Support. Planning and Evaluation of Nature-Based Solutions Projects*; Centre for Ecology and Hydrology: Lancaster, UK, 2017; ISBN 9781906698621.
4. Raymond, C.M.; Frantzeskaki, N.; Kabisch, N.; Berry, P.; Breil, M.; Nita, M.R.; Geneletti, D.; Calfapietra, C. A Framework for Assessing and Implementing the Co-Benefits of Nature-Based Solutions in Urban Areas. *Environ. Sci. Policy* **2017**, *77*, 15–24. [CrossRef]
5. Pineda-Martos, R.; Calheiros, C.S.C. Nature-Based Solutions in Cities—Contribution of the Portuguese National Association of Green Roofs to Urban Circularity. *Circ. Econ. Sustain.* **2021**. [CrossRef]
6. Langergraber, G.; Pucher, B.; Simperler, L.; Kisser, J.; Katsouc, E.; Buehler, D.; Mateo, M.C.G.; Atasanova, N. Implementing Nature-Based Solutions for Creating a Resourceful Circular City. *Blue-Green Syst.* **2020**, *2*, 173–184. [CrossRef]
7. Cohen-Shacham, E.; Walters, G.; Janzen, C.; Maginnis, S. *Nature-Based Solutions to Address Global Societal Challenges*; Cohen-Shacham, E., Walters, G., Janzen, C., Maginnis, S., Eds.; IUCN: Gland, Switzerland, 2016; ISBN 9782831718125.
8. Kabisch, N.; Frantzeskaki, N.; Pauleit, S.; Naumann, S.; Davis, M.; Artmann, M.; Haase, D.; Knapp, S.; Korn, H.; Stadler, J.; et al. Nature-Based Solutions to Climate Change Mitigation and Adaptation in Urban Areas: Perspectives on Indicators, Knowledge Gaps, Barriers, and Opportunities for Action. *Ecol. Soc.* **2016**, *21*, 39. [CrossRef]
9. Ramusino, L.C.; Cortese, M.; Lennard, Z. Re-Naturing the City: Nature4Cities Project to Elevate the Concept of Nature-Based Solutions. *Proceedings* **2017**, *1*, 696. [CrossRef]
10. Ellen MacArthur Foundation. *Delivering the Circular Economy a Toolkit for Policymakers*; Ellen MacArthur Foundation: Cowes, UK, 2015.
11. DEFRA. *The Economics of Waste and Waste Policy*; Department for Environment, Food and Rural Affairs (DEFRA): London, UK, 2011.
12. Agudelo-Vera, C.M.; Leduc, W.R.W.A.; Mels, A.R.; Rijnaarts, H.H.M. Harvesting Urban Resources towards More Resilient Cities. *Resour. Conserv. Recycl.* **2012**, *64*, 3–12. [CrossRef]
13. Lucertini, G.; Musco, F. Circular Urban Metabolism Framework. *One Earth* **2020**, *2*, 138–142. [CrossRef]
14. Atanasova, N.; Castellar, J.A.C.; Pineda-Martos, R.; Nika, C.E.; Katsou, E.; Istenič, D.; Pucher, B.; Andreucci, M.B.; Langergraber, G. Nature-Based Solutions and Circularity in Cities. *Circ. Econ. Sustain.* **2021**, *1*, 319–332. [CrossRef]

15. Castellar, J.A.C.; Popartan, L.A.; Pueyo-Ros, J.; Atanasova, N.; Langergraber, G.; Sämuel, I.; Corominas, L.; Comas, J.; Acuña, V. Nature-Based Solutions in the Urban Context: Terminology, Classification and Scoring for Urban Challenges and Ecosystem Services. *Sci. Total Environ.* **2021**, *779*, 146237. [CrossRef]
16. Hemming, V.; Burgman, M.A.; Hanea, A.M.; Mcbride, M.F.; Wintle, B.C. A Practical guide to structured expert elicitation using the idea protocol. *Methods Ecol. Evol.* **2018**, *9*, 169–180. [CrossRef]
17. Hemming, V.; Walshe, T.V.; Hanea, A.M.; Fidler, F.; Burgman, M.A. Eliciting Improved Quantitative Judgements Using the IDEA Protocol: A Case Study in Natural Resource Management. *PLoS ONE* **2018**, *13*, 1–34. [CrossRef]
18. European Commission. *Towards an EU Research and Innovation Policy Agenda for Nature-Based Solutions & Re-Naturing Cities*; Publications Office of the European Union: Luxembourg, 2015.
19. Maes, J.; Jacobs, S. Nature-Based Solutions for Europe's Sustainable Development. *Conserv. Lett.* **2015**, *10*, 1–4. [CrossRef]
20. Van der Jagt, A.P.N.; Szaraz, L.R.; Delshammar, T.; Cvejić, R.; Santos, A.; Goodness, J.; Buijs, A. Cultivating Nature-Based Solutions: The Governance of Communal Urban Gardens in the European Union. *Environ. Res.* **2017**, *159*, 264–275. [CrossRef] [PubMed]
21. Short, C.; Clarke, L.; Carnelli, F.; Uttley, C.; Smith, B. Capturing the Multiple benefits associated with nature-based solutions: Lessons from a natural flood management project in the cotswolds, UK. *Land Degrad. Dev.* **2019**, *30*, 241–252. [CrossRef]
22. Baganz, G.; Proksch, G.; Kloas, W.; Lorleberg, W.; Baganz, D.; Staaks, G.; Lohrberg, F. Site Resource Inventories-A Missing Link in the Circular City's Information Flow. *Adv. Geosci.* **2020**, *54*, 23–32. [CrossRef]
23. Fletcher, T.D.; Shuster, W.; Hunt, W.F.; Ashley, R.; Butler, D.; Arthur, S.; Trowsdale, S.; Barraud, S.; Semadeni-Davies, A.; Bertrand-Krajewski, J.L.; et al. SUDS, LID, BMPs, WSUD and More–The Evolution and application of terminology surrounding urban drainage. *Urban Water J.* **2015**, *12*, 525–542. [CrossRef]
24. UNALAB. *Nature Based Solutions–Technical Handbook (Part. II)*; UNALAB Project. 2019. Available online: https://unalab.eu/system/files/2020-02/unalab-technical-handbook-nature-based-solutions2020-02-17.pdf (accessed on 30 June 2021).
25. NATURE4CITIES. *NBS Multi-Scalar and Multi-Thematic Typology and Associated Database*; NATURE4CITIES Project. 2020. Available online: https://www.nature4cities.eu/post/nature4cities-multi-scalar-and-multi-thematic-nature-based-solutions-typology (accessed on 30 June 2021).
26. URBANGREENUP. *NBS Catalogue*; URBANGREENUP Project. 2018. Available online: https://www.urbangreenup.eu/news--events/news/the-urban-greenup-catalogue-of-nature-based-solutions-is-now-public_1.kl (accessed on 30 June 2021).
27. Somarakis, G.; Stagakis, S.; Chrysoulakis, N. *ThinkNature Nature Based Solutions Handbook*; European Union: Luxembourg, 2019; pp. 1–226. [CrossRef]
28. Boano, F.; Caruso, A.; Costamagna, E.; Ridolfi, L.; Fiore, S.; Demichelis, F.; Galvão, A.; Pisoeiro, J.; Rizzo, A.; Masi, F. A Review of Nature-Based Solutions for Greywater Treatment: Applications, Hydraulic Design, and Environmental Benefits. *Sci. Total Environ.* **2019**, *711*, 134731. [CrossRef]
29. Kisser, J.; Wirth, M.; De Gusseme, B.; Van Eekert, M.; Zeeman, G.; Schoenborn, A.; Vinnerås, B.; Finger, D.C.; Kolbl Repinc, S.; Bulc, T.G.; et al. A Review of Nature-Based Solutions for Resource Recovery in Cities. *Blue-Green Syst.* **2020**, *2*, 138–172. [CrossRef]
30. Decina, S.M.; Hutyra, L.R.; Templer, P.H. Hotspots of Nitrogen Deposition in the World's Urban Areas: A Global Data Synthesis. *Front. Ecol. Environ.* **2019**, *18*, 92–100. [CrossRef]
31. Barron, O.V.; Barr, A.D.; Donn, M.J. Effect of Urbanisation on the Water Balance of a Catchment with Shallow Groundwater. *J. Hydrol.* **2013**, *485*, 162–176. [CrossRef]
32. McPhillips, L.E.; Matsler, M.; Rosenzweig, B.R.; Kim, Y. What Is the Role of Green Stormwater Infrastructure in Managing Extreme Precipitation Events? *Sustain. Resilient Infrastruct.* **2021**, *6*, 133–142. [CrossRef]
33. Rosenzweig, B.R.; McPhillips, L.; Chang, H.; Cheng, C.; Welty, C.; Matsler, M.; Iwaniec, D.; Davidson, C.I. Pluvial Flood Risk and Opportunities for Resilience. *Wiley Interdiscip. Rev. Water* **2018**, *5*, 1–18. [CrossRef]
34. Hoffmann, S.; Feldmann, U.; Bach, P.M.; Binz, C.; Farrelly, M.; Frantzeskaki, N.; Hiessl, H.; Inauen, J.; Larsen, T.A.; Lienert, J.; et al. A Research Agenda for the Future of Urban Water Management: Exploring the Potential of Nongrid, Small-Grid, and Hybrid Solutions. *Environ. Sci. Technol.* **2020**, *54*, 5312–5322. [CrossRef] [PubMed]
35. Masi, F.; Langergraber, G.; Santoni, M.; Istenič, D.; Atanasova, N.; Buttiglieri, G. Possibilities of nature-based and hybrid decentralized solutions for reclaimed water reuse. In *Advances in Chemical Pollution, Environmental Management and Protection*; Verlicchi, P., Ed.; Elsevier: Amsterdam, The Netherlands, 2020; Volume 5, pp. 145–187.
36. Ma, X.; Xue, X.; González-Mejía, A.; Garland, J.; Cashdollar, J. Sustainable Water Systems for the City of Tomorrow-A Conceptual Framework. *Sustainability* **2015**, *7*, 12071–12105. [CrossRef]
37. Skar, S.L.G.; Pineda-Martos, R.; Timpe, A.; Pölling, B.; Bohn, K.; Külvik, M.; Delgado, C.; Pedras, C.M.G.; Paço, T.A.; Ćujić, M.; et al. Urban Agriculture as a Keystone Contribution towards Securing Sustainable and Healthy Development for Cities in the Future. *Blue-Green Syst.* **2020**, *2*, 1–27. [CrossRef]
38. Kron, W.; Eichner, J.; Kundzewicz, Z.W. Reduction of Flood R„isk in Europe–Reflections from a Reinsurance Perspective. *J. Hydrol.* **2019**, *576*, 197–209. [CrossRef]
39. University of Arkansas Community Design Center. *LID Low Impact Development-a Desing Manual Dor Urban. Areas*; UACDC: Fayetteville, NC, USA, 2010; ISBN 9780979970610.
40. Pan, D.; Gao, X.; Wang, J.; Yang, M.; Wu, P.; Huang, J.; Dyck, M.; Zhao, X. Vegetative Filter strips—Effect of vegetation type and shape of strip on run-off and sediment trapping. *Land Degrad. Dev.* **2018**, *29*, 3917–3927. [CrossRef]

41. Woods-Ballard, B.; Wilson, S.; Udale-Clarke, H.; Illman, S.; Scot, T.; Acheley, R.; Kellagher, R. *The SUDS Manual*; Ciria: London, UK, 2015; ISBN 9780860176978.
42. Xiao, Q.; Gregory McPherson, E.; Zhang, Q.; Ge, X.; Dahlgren, R. Performance of Two Bioswales on Urban Runoff Management. *Infrastructures* **2017**, *2*, 12. [CrossRef]
43. VA-DCR. *Virginia DCR Stormwater Design Specification No. 10: Dry Swales, Version 1.9*. 2011. Available online: http://chesapeakestormwater.net/wp-content/uploads/downloads/2012/02/DCR-BMP-Spec-No-10_DRY-SWALE_Final-Draft_v1-9_03012011.pdf (accessed on 30 June 2021).
44. Grey, V.; Livesley, S.J.; Fletcher, T.D.; Szota, C. Tree Pits to Help Mitigate Runoff in Dense Urban Areas. *J. Hydrol.* **2018**, *565*, 400–410. [CrossRef]
45. Sun, W.; Lu, G.; Ye, C.; Chen, S.; Hou, Y.; Wang, D.; Wang, L.; Oeser, M. The State of the Art: Application of Green Technology in Sustainable Pavement. *Adv. Mater. Sci. Eng.* **2018**, *2018*, 9760464. [CrossRef]
46. Olokeogun, O.S.; Kumar, M. An Indicator Based Approach for Assessing the Vulnerability of Riparian Ecosystem under the Influence of Urbanization in the Indian Himalayan City, Dehradun. *Ecol. Indic.* **2020**, *119*, 106796. [CrossRef]
47. Vacek, P.; Struhala, K.; Matějka, L. Life-Cycle Study on Semi Intensive Green Roofs. *J. Clean. Prod.* **2017**, *154*, 203–213. [CrossRef]
48. Dotro, G.; Langergraber, G.; Molle, P.; Nivala, J.; Puigagut, J.; Stein, O.; Von Sperling, M. *Treatment Wetlands. Biological Wastewater Treatment Series*; Techset, N., Ed.; IWA Publishing: London, UK, 2017; Volume 7, ISBN 9781780408767.
49. Von Sperling, M. *Waste Stabilisation Ponds*; IWA Publishing: London, UK, 2007; Volume 3, ISBN 9781843391630.
50. Gruchlik, Y.; Linge, K.; Joll, C. Removal of Organic Micropollutants in Waste Stabilisation Ponds: A Review. *J. Environ. Manag.* **2018**, *206*, 202–214. [CrossRef]
51. Megharaj, M.; Naidu, R. Soil and Brownfield Bioremediation. *Microb. Biotechnol.* **2017**, *10*, 1244–1249. [CrossRef]
52. Zouboulis, A.I.; Moussas, P.A. Groundwater and Soil Pollution: Bioremediation. *Encycl. Environ. Health* **2011**, 1037–1044. [CrossRef]
53. Olguín, E.J.; Sánchez-Galván, G. Phycoremediation: Current Challenges and Applications. In *Comprehensive Biotechnology*; Moo-youn, M., Ed.; Elsevier: Amsterdam, The Netherlands, 2019; pp. 215–222. ISBN 9780080885049.
54. Kurade, M.B.; Ha, Y.H.; Xiong, J.Q.; Govindwar, S.P.; Jang, M.; Jeon, B.H. Phytoremediation as a Green Biotechnology Tool for Emerging Environmental Pollution: A Step Forward towards Sustainable Rehabilitation of the Environment. *Chem. Eng. J.* **2021**, *415*, 129040. [CrossRef]
55. Van Lier, J.B.; Mahmoud, N.; Zeeman, G. Anaerobic Wastewater Treatment. In *Biological Wastewater Treatment: Principles, Modeling and Design*; Chen, G., Ekama, G.A., van Loosdrecht, M.C.M., Brdjanovic, D., Eds.; IWA Publishing: London, UK, 2020; pp. 415–456. [CrossRef]
56. Metcalf, E. *Wastewater Engineering: Treatment and Reuse*, 4th ed.; McGraw-Hill Education: New York, NY, USA, 2002; ISBN 9780070418783.
57. Fletcher, T.D.; Vietz, G.; Walsh, C.J. Protection of Stream Ecosystems from Urban Stormwater Runoff: The Multiple Benefits of an Ecohydrological Approach. *Prog. Phys. Geogr.* **2014**, *38*, 1–13. [CrossRef]
58. Seidel, M.; Voigt, M.; Langheinrich, U.; Hoge-Becker, A.; Gersberg, R.M.; Arévalo, J.R.; Lüderitz, V. Re-Connection of Oxbow Lakes as an Effective Measure of River Restoration. *Clean-Soil Air Water* **2017**, *45*, 1–9. [CrossRef]
59. Davis, M.; Krüger, I.; Hinzmann, M. Coastal Protection and Suds-Nature-Based Solutions. *Policy Br.* **2015**, *4*, 1–14.
60. Schueler, K. *Nature-Based Solutions to Enhance Coastal Resilience*; Inter-American Development Bank: Washington, DC, USA, 2017; 13p. Available online: https://publications.iadb.org/publications/english/document/Nature-based-Solutions-to-Enhance-Coastal-Resilience.pdf (accessed on 30 June 2021).
61. Stokes, A.; Norris, J.E.; Van Beek, L.P.H.; Bogaard, T.; Cammeraat, E.; Mickovski, S.B.; Jenner, A.; Di Iorio, A.; Fourcaud, T. How vegetation reinforces soil on slopes. In *Slope Stability and Erosion Control: Ecotechnological Solutions*; Norris, J.E., Stokes, A., Mickovski, S.B., Cammeraat, E., van Beek, R., Eds.; Springer: New York, NY, USA, 2008; pp. 65–118. ISBN 9781402066757.
62. Zhao, C.; Zhao, D. Application of Construction Waste in the Reinforcement of Soft Soil Foundation in Coastal Cities. *Environ. Technol. Innov.* **2021**, *21*, 101195. [CrossRef]
63. Kowarik, I. The "Green Belt Berlin": Establishing a Greenway Where the Berlin Wall Once Stood by Integrating Ecological, Social and Cultural Approaches. *Landsc. Urban. Plan. J.* **2019**, *184*, 12–22. [CrossRef]
64. Tang, B.S.; Wong, S.W.; Lee, A.K.W. Green Belt in a compact city: A Zone for conservation or transition? *Landsc. Urban. Plan.* **2007**, *79*, 358–373. [CrossRef]
65. FAO. *Guidelines on Urban. and Peri-Urban. Forestry-FAO Forestry Paper No. 178*; Food and Agriculture Organization of the United Nations (FAO): Rome, Italy, 2016; ISBN 9789251094426.
66. Hoyle, H.; Jorgensen, A.; Warren, P.; Dunnett, N.; Evans, K. "Not in Their front yard" The opportunities and challenges of introducing perennial urban meadows: A Local authority stakeholder perspective. *Urban For. Urban Green.* **2017**, *25*, 139–149. [CrossRef]
67. Oliveras, I.; Malhi, Y. Many Shades of green: The Dynamic tropical forest–savannah transition zones. *Philos. Trans. R. Soc. B Biol. Sci.* **2016**, *371*, 20150308. [CrossRef] [PubMed]
68. Kark, S.; van Rensburg, B.J. Ecotones: Marginal or Central Areas of Transition? *Isr. J. Ecol. Evol.* **2006**, *52*, 29–53. [CrossRef]
69. Roan, E.; Tiu, L.; Yanong, R.; DiMaggio, M.; Patterson, J. Overview of Urban Aquaculture. *Edis* **2019**, *6*, fa217–fa2019. [CrossRef]

70. Christie, E. Water and Nutrient Reuse within Closed Hydroponic Systems. *Electronic Theses and Dissertations* 1096. 2014. Available online: https://digitalcommons.georgiasouthern.edu/etd/1096 (accessed on 30 June 2021).
71. Rufí-Salís, M.; Calvo, M.J.; Petit-Boix, A.; Villalba, G.; Gabarrell, X. Exploring Nutrient Recovery from Hydroponics in Urban Agriculture: An Environmental Assessment. *Resour. Conserv. Recycl.* **2020**, *155*, 104683. [CrossRef]
72. Sambo, P.; Nicoletto, C.; Giro, A.; Pii, Y.; Valentinuzzi, F.; Mimmo, T.; Lugli, P.; Orzes, G.; Mazzetto, F.; Astolfi, S.; et al. Hydroponic Solutions for Soilless Production Systems: Issues and Opportunities in a Smart Agriculture Perspective. *Front. Plant. Sci.* **2019**, *10*, 1–17. [CrossRef]
73. Wongkiew, S.; Hu, Z.; Lee, J.W.; Chandran, K.; Nhan, H.T.; Marcelino, K.R.; Khanal, S.K. Nitrogen Recovery via Aquaponics−Bioponics: Engineering Considerations and Perspectives. *ACS EST Eng.* **2021**, *1*, 326–339. [CrossRef]
74. Allen, W.; Archipley, C.; Biernbaum, J.; Caporelli, A.; Chapman, D.; Cufone, M.; Lamendella, A.; Shultz, C.; Sideman, E.; Sleiman, P.; et al. *National Organic Standards Board (NOSB)-Hydroponic and Aquaponic Task Force Report*; United States Department of Agriculture: Washington, DC, USA, 2016.
75. Baganz, G.F.M.; Junge, R.; Portella, M.C.; Goddek, S.; Keesman, K.J.; Baganz, D.; Staaks, G.; Shaw, C.; Lohrberg, F.; Kloas, W. The Aquaponic Principle-It Is All about Coupling. *Rev. Aquac.* **2021**. [CrossRef]
76. Andersen, R.A. (Ed.) *Algal Culturing Techniques*; Elsevier: Amsterdam, The Netherlands, 2005.
77. Gupta, P.L.; Lee, S.M.; Choi, H.J. A Mini Review: Photobioreactors for Large Scale Algal Cultivation. *World J. Microbiol. Biotechnol.* **2015**, *31*, 1409–1417. [CrossRef]
78. Ackerman, K.; Conard, M.; Culligan, P.; Plunz, R.; Sutto, M.P.; Whittinghill, L. Sustainable Food Systems for Future Cities: The Potential of Urban Agriculture. *Econ. Soc. Rev.* **2014**, *45*, 189–206.
79. Campisano, A.; Butler, D.; Ward, S.; Burns, M.J.; Friedler, E.; DeBusk, K.; Fisher-Jeffes, L.N.; Ghisi, E.; Rahman, A.; Furumai, H.; et al. Urban Rainwater Harvesting Systems: Research, Implementation and Future Perspectives. *Water Res.* **2017**, *115*, 195–209. [CrossRef] [PubMed]
80. Hallas, J.F.; Mackowiak, C.L.; Wilkie, A.C.; Harris, W.G. Struvite Phosphorus Recovery from Aerobically Digested Municipal Wastewater. *Sustainability* **2019**, *11*, 376. [CrossRef]
81. Gabhane, J.W.; Bhange, V.P.; Patil, P.D.; Bankar, S.T.; Kumar, S. Recent Trends in Biochar Production Methods and Its Application as a Soil Health Conditioner: A Review. *SN Appl. Sci.* **2020**, *2*, 1–21. [CrossRef]